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**THE EXPERIMENTAL CLEAN COMBUSTOR PROGRAM -
DESCRIPTION AND STATUS TO NOVEMBER 1975**

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For inclusion in "THE RULES DOCKET" for the 1976 review
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THE EXPERIMENTAL CLEAN COMBUSTOR PROGRAM -
DESCRIPTION AND STATUS TO NOVEMBER 1975

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SUMMARY

The Experimental Clean Combustor Program is a multi-year contract effort. Primary program objectives are the generation of technology for the development of advanced commercial CTOL aircraft engines with lower exhaust emissions than current aircraft, and demonstration of this technology in full-scale engines in 1976. The program is administered by the NASA Lewis Research Center and is being conducted by two contractors. Low pollution engine-combustors are being evolved by the General Electric Company for the CF6-50 engine and by Pratt & Whitney Aircraft for the JT9D-7 engine.

The program is being conducted in three phases. Phase I, already completed, consisted of screening tests of low pollution combustor concepts. Phase II, currently in progress, consists of test rig refinement of the most promising combustor concepts. Phase II test results form the major basis of this report. Phase III, also currently in progress, consists of incorporating and evaluating the best combustors as part of a complete engine. Engine test plans and pollution sampling techniques are described in this report.

Program pollution goals, specified at engine idle and take-off conditions, are idle emission index values of 20 and 4 for carbon monoxide (CO) and total unburned hydrocarbons (THC), respectively, and at take-off are an oxides of nitrogen (NO_x) emission index level of 10 and a smoke number of 15. Pollution data were obtained at all engine operating conditions. Results are presented in terms of emission index and also in terms of the Environmental Protection Agency's 1979 Standards Parameter (EPAP).

In Phase II, each contractor investigated two combustor concepts. All combustor concepts incorporated multi-burning zones, produced substantial reductions of gaseous pollutants and achieved the goal smoke level. General Electric evaluated double/annular and radial/axial combustor concepts. The best

double/annular configuration exceeded the idle pollution goals producing emission index values of CO and THC of 19 and 2.2, respectively. Although the NO_x goal was not achieved, a substantial reduction of over 50 percent, compared to the reference production CF6-50 engine, was achieved. On an EPAP basis, this configuration produced values of 3.01 for CO, 0.31 for THC, and 4.15 for NO_x . In addition, this configuration demonstrated altitude relight characteristics comparable to the reference design, did not appear to have any carboning or durability problems and did not appear to have any unsolvable exit temperature distribution problems. Radial/axial combustor pollutant reductions while substantial, were not as large as those of the double/annular design. This combustor experienced flashback and durability problems. On the basis of these results, the double/annular combustor was selected as the most promising concept and the one most readily adaptable to engine installation.

Pratt & Whitney evaluated a vorbix and a hybrid combustor concept. The best vorbix configuration approached the CO and NO_x goals and exceeded the THC goal. Emission index values of 26.4 for CO, 3.5 for THC, and 14.6 for NO_x were demonstrated. On an EPAP basis, this configuration produced values of 6.25 for CO, 0.64 for THC, and 3.48 for NO_x . In addition, the vorbix combustor produced altitude relight characteristics comparable to JT9D-7 rig data and did not appear to have any unsolvable durability or exit temperature distribution problems. The hybrid combustor produced comparable pollutant reductions but demonstrated poor altitude relight characteristics. On the basis of these results, the vorbix combustor was selected as the most promising concept and the one most readily adaptable to engine installation.

Up to the present, all combustor testing has been in component test rigs. It appears that two promising low-pollution combustor designs, the General Electric double/annular design and the Pratt & Whitney vorbix design, suitable for engine installation have been developed. However, verification of the pollution reductions achieved as well as the practicality of the designs await the Phase III engine demonstration tests wherein the low pollution combustors will be evaluated as components of the CF6-50 and the JT9D-7 engines.

INTRODUCTION

This report describes the results of combustor component testing obtained to date for the Experimental Clean Combustor Program. Also described are the

program's objectives, program plan, schedule, pollution and performance goals, the pollution reduction approaches investigated, and future program efforts emphasizing demonstration tests of low-pollution combustors installed in full-scale engines.

While considerable progress has been made in reducing the smoke levels of gas turbine engines, no combustors for current aircraft incorporate design features specifically for the reduction of gaseous pollutants. The Environmental Protection Agency has published standards which require substantial reduction of gaseous pollutants by 1979. The pollutants in question are oxides of nitrogen formed primarily during high power engine operation and carbon monoxide and total unburned hydrocarbons formed primarily during low power engine operation.

It appears that substantial reduction of pollutants can be attained. The concepts for pollution reduction now exist. However, although the mechanisms of pollution production as well as techniques for reducing pollutants are generally known, application of these techniques to specific engine-combustor designs have not yet demonstrated the anticipated pollutant reductions without compromising other combustor parameters. Thus additional technology was needed to apply these concepts. Therefore, the "Experimental Clean Combustor Program" was initiated since no other program aimed at timely evolution of "clean" combustors existed.

The program aim is to develop this required pollution reduction technology. This will be accomplished by evaluating the most promising pollution reduction techniques through combustor component resting, solving interface and performance problems which low pollutant combustor designs create for engine installation, and demonstrating the pollution reductions in high pressure ratio CTOL engines in 1976.

PROGRAM DESCRIPTION

General

The "Experimental Clean Combustor Program" is a multi-year contract effort administered by the NASA-Lewis Research Center and conducted by two contractors: The General Electric Company of Evendale, Ohio; Pratt & Whitney Aircraft of East Hartford, Connecticut. The program's primary objectives are the following:

1. To generate and demonstrate the technology required to develop advanced commercial CTOL aircraft engines with lower exhaust pollutant emissions than are possible with current technology.

2. To demonstrate the emission reductions in full-scale engines in 1976.

Although pollution reduction investigations are being conducted with combustors sized to fit within the GE CF6-50 and the P&W JT9D-7 engines, the program is aimed at generating technology primarily applicable to advanced commercial engines with overall compressor pressure ratios of 20 to 35. This technology should also be applicable to military engines. Specifically, the program emphasizes pollution reduction through combustor design. Gaseous pollutant reductions are emphasized since commercial engines currently produce smoke emissions which are below visible thresholds.

Program Plan

The program is being conducted in three sequential, individually funded phases. The planned program schedule is shown in table I. Program phases consist of the following:

Phase I: Combustor screening. - Phase I efforts were initiated in December 1972, and have been completed. Phase I consisted of component combustor test rig screening of various combustor designs to determine the most promising combustor concepts based on pollutant emission characteristics and performance. Interim Phase I program status is described in reference 1. Phase I program results are detailed in the Contractor Reports contained in references 2 and 3. Results of combustion noise addendum studies performed concurrent with Phase I testing are contained in references 4 and 5.

Phase II: Combustor refinement and optimization. - Phase II efforts were initiated in July 1974, are currently in progress and are nearing completion. Phase II results form the major basis for this report. This phase consists of refinement and optimization of the best Phase I combustor designs through test rig component evaluations in order to establish required overall combustor performance, durability, and engine adaptability.

Phase III: Combustor-engine testing. - Phase III efforts were initiated in June 1975, and are scheduled for completion in 1976. Phase III consists of tests of each contractor's best Phase II combustor as part of a complete engine. Engine testing is aimed at authentication of pollution reductions as well as de-

termination of low-pollution engine-combustor acceleration/deceleration characteristics.

Program Goals

Inasmuch as smoke emissions have been reduced to below the visible threshold on current commercial engines, program focus is directed towards reduction of gaseous pollutants of oxides of nitrogen, total unburned hydrocarbons, and carbon monoxide. However, further reductions in smoke and particulate emissions are also sought. These pollutant reductions must be accomplished with a minimum and acceptable sacrifice of conventional combustor performance parameters.

Pollution goals. - Criteria used for selecting pollution goals were the following: The goals represent optimistic projections of achievable pollutant reductions. The goals are currently beyond combustor design state-of-the-art, and, in order to be achieved, require pollutant reductions by factors of three to seven for the CF6-50 and the JT9D-7 engines.

Combustor exhaust pollutant goals in terms of engine operating modes are listed in table II. Gaseous pollutant goals for oxides of nitrogen or NO_x ($\text{NO}_x = \text{NO} + \text{NO}_2$), carbon monoxide, CO, and total unburned hydrocarbons, THC, are expressed in terms of emission index. Emission index is the ratio of grams of pollutant formed per kilogram of fuel consumed. Smoke and particulate concentrations are expressed in terms of the SAE smoke number. Idle and take-off operating modes represent standard day engine operating conditions. Pollution data obtained during combustor component testing (program Phases I and II) at simulated engine conditions but of reduced pressure, require extrapolation to indicate concentrations at engine conditions.

For comparative purposes, the Environmental Protection Agency 1979 Standards for T-2 class engines, estimated on an emission index basis, are also included in table II. T-2 class engines have been defined by the Environmental Protection Agency as turbofan or turbojet engines with 8000 pounds thrust or greater, excluding the JT-3D and the JT-8D model families as well as supersonic transport engines. The NO_x emission index value was back calculated from the EPA Standard by assuming that NO_x emission index values at taxi-idle and approach conditions are unchanged and that climbout values equal 75 percent of the computed take-off value. A comparison of standards

and program pollutant values show that the idle pollutant values are quite close. The major variance occurs in the NO_x value where the program goal is lower, 10 as opposed to 13 for the 1979 EPA standards.

Also contained in table II are engine emissions data for the JT9D-7 and the CF6-50 engines. These data indicate that reductions by factors of three to seven are required to achieve program goal values.

The Environmental Protection Agency parameter values (EPAPS) for CO, THC, and NO_x are contained in table III. Listed are the 1979 EPAP required values for T-2 class engines, current EPAP values for the CF6-50 and JT9D-7 engines, and the percentages that current engine values exceed the required values. As can be seen, substantial reductions are required for all pollutants. Subsequent report sections describe emissions data both in terms of emission index and EPAP.

Performance goals. - Key combustor performance goals are listed in table IV. With the exception of combustion efficiency and possibly pattern factor, these goals represent values achievable with current aircraft engines. Thus, these goals represent limits up to which these values can be increased in pursuit of the pollution goals. With current aircraft, combustion efficiencies of 99 percent are not achieved at the taxi-idle condition. Combustion efficiencies of 99 percent or higher are required at all engine conditions to achieve the program pollution goals.

Program Approaches to Pollution Reduction

The greatest concentrations of gas turbine pollutants are formed at the two extremes of the engine operating power range. Thus, pollutant control involves minimizing pollutant formation at both low power conditions as typified by engine idle as well as at high power or take-off. If pollutant formation can be significantly reduced at the extreme engine operating modes, then corresponding reductions in pollutants could be realized at intermediate engine operating modes such as descent, cruise, and climbout. For the above reasons, pollution goals were selected at and combustor evaluations were conducted primarily at simulated engine idle and take-off conditions in Phase I. In Phase II, combustors are being evaluated at conditions simulating all engine operational modes.

Idle pollutants. - Incomplete combustion is the principal cause of idle pollutants. The principal pollutants at idle are carbon monoxide, CO, and unburned

hydrocarbons, THC, either as raw fuel or as partially oxidized fuel. The latter are primarily responsible for the characteristic odor common to all airports (ref. 6). Aircraft combustors are designed for maximum performance at take-off and cruise conditions. Operation at low power conditions generally results in lower combustion efficiencies and, as a result, in higher pollutant emissions. Typical combustion efficiencies at idle vary between 88 and 96 percent; the actual values are dependent on engine size, type, and age, as well as operational procedures such as the amount of power extracted and the amount of compressor air bleed used.

Low combustion efficiency at idle results primarily from the poor burning conditions encountered. Low combustor inlet air temperatures, typically 366 to 466 K cause quenching to occur thus terminating combustion before completion. Low pressures, typically 2 to 4 atmospheres, reduce burning intensity. The low fuel-air ratios required at idle, typically 0.010 to 0.013, result in low primary zone equivalence ratios reducing burning intensity as well as causing poor fuel atomization and distribution. Equivalence ratio is the ratio of local fuel-air ratio to the fuel-air ratio at stoichiometric combustion which is 0.0676 for ASTM jet A fuel. In addition, the low volatility of commercial aircraft kerosene fuel further aggravates the problem.

High power pollutants. - Combustor pressure, inlet air temperature, and fuel-air ratio increase as the power level of a gas turbine engine is increased. At full power, the combustion efficiency is nearly 100 percent and negligible levels of carbon monoxide and unburned hydrocarbons exist. However, the higher temperature and pressure levels within the combustor lead to the generation of smoke and oxides of nitrogen.

Reduction of smoke and particulate matter has received a great deal of attention in recent years and new gas turbine engines generate little, if any, visible smoke. Smoke reduction was accomplished principally by reducing combustor primary zone fuel-air ratio thereby eliminating large, fuel-rich zones.

Redesigning gas turbine combustor so that they produce significantly reduced oxides of nitrogen levels is a difficult task. Oxides of nitrogen are natural products of combustion forming during all combustion processes involving air. The formation of oxides of nitrogen in combustors is relatively well understood and has been the subject of many technical reports (refs. 7 to 9). The amount formed is controlled by the chemical reaction rate and is a function of the flame temperature, residence time of combustion gases at the highest temperatures, the concentrations of oxygen and nitrogen present, and, to a lesser extent, the combustor pressure.

Combined pollution considerations. - Table V highlights some of the difficulties encountered in applying pollution reduction techniques. Because of the large changes in combustor environment between low power and high power engine operating modes, and also because of differences in mechanisms for production of the pollutants at these operating modes, techniques which reduce pollutants at one condition can increase pollutants at the other condition. An exception is improvement in fuel preparation and distribution which could produce better control of the combustion reactions thereby reducing pollutants at both power modes.

Program pollution reduction approaches. - Three main pollution reduction approaches are being pursued in this program. Each approach appears to contain the potential for reducing pollutants at all engine operating conditions. The approaches are being investigated individually and in combination. The approaches are:

Multiple Burning Zones: In this approach combustion is split into two burning zones, a pilot burner optimized for low power operation, and a main burner optimized for high power operation. Pilot burner equivalence ratios are near 1 at idle with mixing of combustion gases with diluent air delayed. Main burner equivalence ratios are 0.5 to 0.8 at take-off with increased and quick mixing of combustion gases and diluent air. Only the pilot burner is fired during operation at low power conditions. Both burning zones, with fuel reduced to the pilot burner, are fired during high power operation.

Two types of multiple burning zone combustors are being investigated. In one type, each burning zone operates independently of the other. In the other type, burners are coupled. For example, hot gases from the pilot burner are used to increase combustion stability and vaporize fuel for the main burner.

Improved Distribution and Preparation of Fuel: The purpose of fuel distribution and preparation studies are to provide fuel systems which better control fuel-air mixture uniformity as well as mixture strength. The following methods are being employed:

1. Increased number of fuel sources.
2. Advanced fuel-air atomization techniques.
3. Premixing of fuel and air upstream of the burning zones.
4. Prevaporization of fuel upstream of the burning zones.

Fuel staging is also being investigated. Fuel is being staged radially, axially, and in combustor sectors at low power conditions. Staging fuel consists of supplying fuel to some but not all of the fuel injectors. Staging fuel improves

atomization, increases local burning intensities, and minimizes quenching interfaces between combustion gases and diluent air.

Combustor Air Distribution: Effects of combustor air staging are being determined by proportionating airflow with combustor blockage to produce optimum pollution reduction conditions at either low or high power conditions.

Program applications of these techniques are described in the next section of this report.

ENGINE-COMBUSTOR CONCEPTS

Reference Engine-Combustors

All of the low-pollution combustion concepts investigated in this program were configured to fit within the contractors engine-combustor envelope, and designed to operate at engine environment conditions. Contained below are descriptions of the Pratt & Whitney JT9D-7 engine and the General Electric CF6-50 engine. More detailed descriptions are contained in references 2 and 3.

JT9D-7 engine-combustor. - the JT9D-7 engine is an advanced, dual-spool, axial flow turbofan engine designed with a high overall compression ratio and a high bypass ratio. The mechanical configuration is shown schematically in figure 1. Since its introduction into commercial service, this engine has acquired widespread use as the powerplant for both the Boeing 747 and the Douglas DC-10-40 aircraft.

The engine consists of five major modules: a fan and low-pressure compressor module, a combustor module, a high-pressure turbine module, and a low-pressure turbine module. The low-pressure spool consists of a single stage fan and a three-stage, low-pressure compressor driven by a four-stage, low-pressure turbine. The high-pressure spool consists of an eleven-stage, high-pressure compressor driven by a two-stage, high-pressure turbine. The accessory gearbox is driven through a towershaft located between the low- and high-pressure compressors. Selected key specifications for the JT9D-7 engine are listed in table VI.

The mechanical design of the JT9D-7 reference combustor is shown schematically in figure 2. The combustor is annular in design with an overall length between the trailing edge of the compressor exit guide vane to the leading edge of the turbine inlet guide vane of 0.6 meter. The actual burning length between the fuel nozzle face and the turbine inlet guide vane leading edge is 0.45

meter. Key performance parameters of the JT9D-7 reference combustor are summarized in table VII.

CF6-50 engine-combustor. - The CF6-50 engine is a dual-rotor, high-bypass ratio turbofan incorporating a variable stator, high-pressure ratio compressor, an annular combustor, an air-cooled core engine turbine, and a coaxial front fan with a low-pressure turbine. The CF6-50 engine is in commercial service as the powerplant for the McDonnell-Douglas DC-10 Series 30 Tri-Jet long range intercontinental aircraft and the Airbus Industrie A300B aircraft.

Basic engine sections are shown in figure 3. The engine consists of a fan section, compressor section, combustor section, turbine section, and accessory drive section. This high bypass turbofan engine has a high thrust-to-weight ratio and favorable fuel economy characteristics. The key overall specifications of the CF6-50 engine are presented in table VIII.

The mechanical design of the CF6-50 reference combustor, as installed in the engine, is shown schematically in figure 4. The key features of this combustor are its low-pressure loss step diffuser, its carbureting swirl cup dome design, and its short burning length. Several of the more important design parameters of this combustor are presented in table IX.

Low-Emission Combustor Concepts

Contained below are descriptions of the combustor concepts evaluated in program Phases I and II.

Pratt & Whitney JT9D-7 combustor concepts. - 90° sectors of combustors, of the JT9D-7 engine-combustor size were evaluated in both program phases.

Phase I Combustor Designs: Thirty-two configurations of three distinct combustor concepts were evaluated. The concepts are shown schematically in figure 5 and are described below.

1. Swirl-can Combustor - As in all swirl-can combustors, all combustor airflow exclusive of liner coolant air, passes either through or around the combustor modules and thus through the primary burning zone. Each swirl-can consists of three major components; a carburetor, swirler, and a flame stabilizer. In operation, fuel and air enter the carburetor, mix in passing through the swirler, and burn in the wake of the flame stabilizer. The combustor consists of a 3-row array simulating 120 swirl-cans for the entire annulus. Module diameters vary between rows with the largest modules placed on the

outer row. This arrangement provides maximum stability and corresponding minimum carbon monoxide and unburned hydrocarbon emissions during low-power operation where only the outer module row is fueled.

Combustor modifications included variations in the three module components as well as variations in fuel entry techniques and swirl-can equivalence ratios.

2. Staged Premix Combustor - This combustor consists of multiple burning zones; a pilot or low-power burner, and a main burner. Each burner has its own fuel injectors, premix passage, flameholder, and combustion volume. The main pollution reduction features contained in this combustor are the premix passages. Their purpose is to control fuel-air mixture uniformity and strength.

Idle power is furnished by supplying fuel to only the pilot burner. Both burners are fueled at high power. The two premix passages and combustion zones are axially displaced with the pilot zone located upstream of the main zone. This placement avoids rapid quenching of the pilot zone combustion gases by main zone air.

Combustor modifications emphasized staging of fuel and air between the combustion zones as well as varying the diluent air.

3. Vorbix Combustor - This combustor also employs two burning zones, a pilot, and a main zone, located along the combustor axis. Air and fuel splits between zones are configured so that the pilot burner only is fueled at idle conditions. At high-power conditions, main burner fuel is introduced at the exit of the pilot zone where it is vaporized. Air required for main zone burning is introduced through swirlers located on both combustor liners. Modifications emphasized fuel and air splits between burning zones as well as location and number of main zone fuel sources.

Detailed test results for all three combustor concepts are contained in reference 3. Although all program goals were not achieved with any of the concepts, all concepts produced significant pollutant reductions.

Lowest emissions at idle engine conditions were obtained with the staged premix combustor. The carbon monoxide emission index level was 55 percent below the goal and the total hydrocarbon emission index level was 75 percent below the goal. The Vorbix combustor approached but did not meet the goals. The swirl-can combustor provided significantly higher idle emissions that were close to the levels produced by current production JT9D-7 combustors.

At sea-level take-off conditions, although none of the combustors was able to meet the goal for oxides of nitrogen, several combustor configurations provided significant reductions relative to the production combustor. The best results were obtained with the vorbix and the swirl-can combustors, both of which provided approximately 60 percent lower emissions of nitrogen oxides than the current production JT9D-7 combustor. All three combustor concepts met the smoke goal.

Combustor performance data indicated the need for substantial improvement. The vorbix and swirl-can combustors operated with combustion efficiencies of 99.5 percent or higher at take-off conditions. The staged premix combustors had lower efficiencies at take-off conditions. Both the swirl-can and the staged premix combustors require development to meet the current JT9D-7 engine altitude relight requirements.

Phase II Combustor Designs: Based on Phase I results, two combustor concepts were selected for Phase II evaluation. These combustors are described below.

1. Vorbix Combustor - The Phase II vorbix combustor design is shown schematically in figure 6(a) and pictorially in figure 6(b). This design evolved from Phase I testing and incorporated several modifications. These are: the pilot burner length was increased to reduce carbon monoxide and unburned hydrocarbon emissions; to reduce oxides of nitrogen formation, the main burner length was shortened, liner height was reduced, and the throat height connecting the pilot and main burners was reduced. A listing of the Phase II vorbix configurations evaluated to date is contained in appendix A. Data tables for all evaluated configurations are contained in appendix B.

2. Hybrid Combustor - The hybrid combustor is shown schematically in figure 7(a) and pictorially in figure 7(b). This design represents an attempt to combine the best features of two of the Phase I designs: a staged premix pilot burner which produced low pollutants at idle conditions; a swirl-can main burner which produced low pollutants at take-off conditions. A listing of evaluated Phase II hybrid configurations is contained in appendix A. Data tables for evaluated configurations are contained in appendix C.

To date, the Pratt & Whitney Phase II test program is approximately two-thirds complete. Both combustor designs have been evaluated and the vorbix design has been selected as the one most promising and most readily adaptable for engine installation. Further Phase II testing will be used to optimize this design for Phase III engine installation.

General Electric CF6-50 combustor concepts. - Full-annular combustor designs, conforming to CF6-50 dimensions, were utilized to determine pollution levels and combustor performance. Sector rigs were also utilized for specialized testing: altitude relight tests were performed in a 60° sector; high-pressure durability and carboning tests were performed in a 13° sector.

Phase I Combustor Designs: Thirty-four configurations of four combustor concepts, including specialized testing of the CF6-50 design, were investigated. The combustor concepts are shown schematically in figure 8 and are described below.

1. Specialized testing of the standard CF6-50 combustor was undertaken to validate test facility pollutant sampling techniques and to assess the effectiveness of various fuel and air staging techniques in reducing low-power pollutants.

2. Single Annulus Lean Dome Combustor - The standard CF6-50 combustor was modified to produce extremely lean primary zone equivalence ratios. This was accomplished by eliminating the diluent air and passing all of the combustor airflow through the primary zone. The lean primary zone tests, along with the reference CF6-50 tests, evaluated the potential of incorporating variable geometry into standard combustor designs.

3. Swirl-can Combustor - A 2-row swirl-can combustor was evaluated by General Electric. Combustor features are similar to the Pratt & Whitney design differing principally in the reduced number of swirl-cans and swirl-can rows in the array. General Electric evaluated arrays consisting of 60, 72, and 90 modules.

4. Radial/Axial Staged Combustor - This combustor incorporates multiple burning zones; a pilot burner of conventional design, and a main burner incorporating a premix passage. Combustor operation is staged with only the pilot burner fueled at low-power conditions and both burners fueled at high-power conditions. Main zone burning is stabilized by V-gutter-type chutes located at the end of the premix passage. Combustion gases from the pilot burner are used to enhance main burner combustion stability, permitting operation to low main zone equivalence ratios.

5. Double Annular Lean Dome Combustor - This combustor incorporates two parallel burning zones. In operation, only the outer annulus is fueled at low-power conditions. Both annuli are fueled at high-power conditions. Combustor modifications emphasized fuel nozzle type, fuel and air distribution, and diluent air introduction.

Phase I detailed test results are contained in reference 2. All program goals were not achieved with any of the combustor concepts. CF6-50 combustor tests demonstrated that substantial pollutant reductions approaching goal values are achievable at engine idle by sector burning the fuel. No NO_x reductions at take-off were obtained. Swirl-can combustors produced only minimal pollutant reductions at both idle and take-off conditions. The double/annular and radial/axial combustor designs achieved idle pollution goal values and reduced NO_x baseline take-off levels by approximately 50 percent.

Phase II Combustor Designs: Based on Phase I results, the double/annular and radial/axial combustors were selected for Phase II evaluation. The Phase II designs incorporate minor modifications of the Phase I designs and are discussed below.

1. Double Annular Combustor - The Phase II double/annular combustor is shown schematically in figure 9(a) and pictorially in figure 9(b). Figure 9(c) is a photograph of the 60° altitude relight sector which illustrates the combustor's front end. A listing of Phase II configurations is contained in appendix A. Data tables for all evaluated configurations are contained in appendix D.

2. Radial/Axial Combustor - The Phase II radial/axial combustor design is shown schematically in figure 10(a) and pictorially in figure 10(b). A listing of the Phase II configurations is contained in appendix A. Data tables for all evaluated configurations are contained in appendix E.

The General Electric Phase II test program has been completed. Both combustor designs have been evaluated and the double/annular design has been selected as being the most promising and most readily adaptable to engine installation.

TEST CONDITIONS, PROCEDURES, AND DATA ANALYSIS

Test Conditions

Combustor pollution and performance testing were performed at actual engine operating conditions, simulated engine operating conditions and parametric variations about the reference engines operating conditions. In these tests, the combustor inlet temperatures, reference velocities, fuel-air ratios, and turbine cooling air extraction rates of the reference combustors were exactly duplicated. Combustor inlet pressure levels were also duplicated at the

idle condition. However, pressure levels were reduced, relative to those of the reference engines, at approach, climbout take-off and simulated cruise due to test rig airflow/pressure limitations. In these cases, airflow rates were correspondingly reduced to maintain the true reference velocities.

Pratt & Whitney test rig conditions are shown in table X. General Electric test rig conditions are shown in table XI. Also included in these tables for comparison are the reference engine-combustor conditions where they differ from the test rig conditions.

Altitude relight testing was conducted at conditions simulating the engine-combustor relight map. Relight factors investigated were lean blowout, relight, and cross-fire.

Data Acquisition

Data acquisition procedures were designed for expedient data acquisition for all engine operating modes. Pollution data were obtained at the combustor exit plane by utilizing multi-point traversing rakes. Samples were recorded by on-line gas analysis equipment consisting of Beckman Model 402 flame ionization detectors for total unburned hydrocarbon measurement, nondispersive infrared (NDIR) instruments for measurement of carbon monoxide and carbon dioxide, and chemiluminescence analyzers for measurement of nitric oxide and nitrogen dioxide. Smoke emissions were measured by filter strain methods.

Combustor exit temperature distributions were determined by multi-point traversing rakes. Sufficient combustor instrumentation was provided to assess combustor performance and status during test runs. All data were recorded by on-line computing systems. Additional details regarding instrumentation, sampling techniques, probe designs, procedures, etc. and contained in references 2 and 3.

Data Analysis

Test rig data are contained in appendixes B through E in sections entitled "1. Test Rig Data". In setting test point conditions, it was rarely possible to operate precisely at the design point fuel-air ratio. Thus, when more than one fuel-air ratio was investigated at a test condition, the general procedure

used was to plot the emissions against fuel-air ratio and determine emission levels at the design point fuel-air ratio by interpolation. When only one fuel-air ratio was investigated at a test condition, emission levels at that value are reported.

Combustion efficiencies were calculated from concentrations of carbon monoxide and total unburned hydrocarbons in the combustor exhaust gases. A carbon monoxide level of 42.7 is equivalent to a 1-percent combustion inefficiency. An unburned hydrocarbon level of 10 is equivalent to a 1-percent combustion inefficiency. Exhaust gas sample validity was constantly monitored during test runs by comparing calculated carbon balance fuel-air ratio values with metered values.

Data Correlation Procedures

Correlations extrapolating test rig data to reference engine conditions were required in order to permit comparisons of test rig results with program goals, EPAP requirements, and with current reference engine levels. Correlations were required for the following reasons:

1. In the test rigs it was not possible to duplicate engine pressure levels greater than idle.
2. Since it was rarely possible to set design point values precisely in the test rigs, it was necessary to normalize the data to the design points.

Generally, pressure correlations from test rig to engine values, especially for higher engine power points, produced large differences in pollution data. Normalization of test rig to engine parameters of inlet temperature, reference velocity, inlet-air humidity, and combustor exit temperatures for NO_x correlation produced small differences, in the aggregate ordinarily within several percentage points, with the exception of inlet-air humidity corrections of the Pratt & Whitney rig data. Pratt & Whitney inlet-air humidity corrections produced NO_x reductions of 8 to 10 percent.

Test rig data extrapolated to engine conditions are contained in appendixes B through E under sections entitled "2. Data corrected to engine pressures", and are discussed in succeeding report sections. The correlations used are described below.

Oxides of nitrogen correlation. - The NO_x correlation parameter used has been previously described in references 3 and 10 and is given below:

$$\text{NO}_x \text{ Eng} = (\text{NO}_x \text{ Rig}) \left(\frac{P_{\text{Eng}}}{P_{\text{Rig}}} \right)^n \left(\frac{V_{\text{ref, Eng}}}{V_{\text{ref, Rig}}} \right) \left(\frac{T_{\text{exit, Eng}}}{T_{\text{exit, Rig}}} \right) \left(e^{\frac{T_{\text{inlet, Eng}} - T_{\text{inlet, Rig}}}{288}} \right) \times e^{\left[-0.0018(6.29 - H_{\text{Rig}}) \right]}$$

where subscripts:

| | |
|--------------------|--|
| Eng | engine design point values |
| Rig | test rig values |
| P | inlet total pressure, atm |
| V _{ref} | reference velocity, m/sec |
| T _{exit} | combustor exit average temperature, K |
| T _{inlet} | combustor inlet temperature, K |
| H | inlet-air humidity (normalized to a humidity level of 6.29 g/kg which corresponds to 60 percent relative humidity on a standard day) |
| n | inlet pressure ratio exponent, (=0.2 or 0.5) |

Two values were used for the inlet pressure ratio exponent n . For the majority of the data, exclusive of engine approach data where only the pilot was fired, the exponent was 0.5. This value is consistent with the value used in references 3 and 10. For approach data with the pilot only fired, an exponent of 0.2 was used. This exponent was derived from Phase II data by General Electric personnel and resulted from a statistical analysis of test data. Verification data for this exponent are contained in table XII and figure 11.

Total unburned hydrocarbon correlation. - Total unburned hydrocarbons were correlated from test rig to engine pressures by the following expression:

$$\text{THC}_{\text{Eng}} = \text{THC}_{\text{Rig}} \left(\frac{P_{\text{Rig}}}{P_{\text{Eng}}} \right)$$

Verification data for this expression, developed by General Electric personnel with Phase II data, are contained in table XII and figure 12. No correlations except the inlet-pressure correction were made to the total unburned hydrocarbon data.

Carbon monoxide correlation. - Test rig carbon monoxide levels were correlated to engine pressure levels by the following expression:

$$CO_{Eng} = CO_{Rig} \left(\frac{P_{Rig}}{P_{Eng}} \right)^N$$

where

$$N = x \left(\frac{CO_{Rig}}{100} \right)^{-0.7}$$

and x equals 0.6 for pilot only operation, and 0.2 when both burning zones are fired. Verification data for this expression, developed by General Electric with Phase II data, are contained in table XII and figure 13. Only inlet-pressure corrections were made to the carbon monoxide data.

EPAP Calculations

The data and calculations presented below were obtained from General Electric and Pratt & Whitney. This material describes the data inputs and calculations required for calculating EPAP values for the CF6-50 and JT9D-7 engines.

General Electric EPAP calculation. - Production engine CF6-50 standard day status cycle data are presented in table XIII. The idle data were obtained from a status deck matched to 109 production engines. The high-power cycle data were obtained from a cycle deck matched to 17 production engines.

EPAP Calculation Procedure: A standard procedure for calculating emissions levels, in terms of the parameter (EPAP) used by the EPA in defining standards for the test configurations has been developed. The prescribed procedure is:

$$EPAP_i = \frac{\sum_j \left(\frac{t_j}{60} \right) \left(\frac{W_{F_j}}{1000} \right) (EI_{ij})}{\sum_j \left(\frac{t_j}{60} \right) \left(\frac{F_{N_j}}{1000} \right)} \quad (1)$$

where

EI emissions index (g/kg fuel)

EPAP emissions parameter (g/kg thrust-hr)

F_N net thrust (KN)

t prescribed time (min)

W_F fuel flow rate (g/s)

and the subscripts are

i type of emissions (CO, HC, NO_x)

j prescribed power level (idle, approach, climbout, and take-off)

For a particular engine cycle, equation (1) can be reduced to:

$$EPAP_i = \sum_j (C_j) (EI_{ij}) \quad (2)$$

where

$$C_j = \frac{\left(\frac{t_j}{60} \right) \left(\frac{W_{F_j}}{1000} \right)}{\left(\frac{t_j}{60} \right) \left(\frac{F_{N_j}}{1000} \right)} \quad (3)$$

The coefficients (C_j) for the CF6-50C cycle are derived in table XIV and equation (2) becomes

$$\begin{aligned} \text{EPAP}_i = & 0.1365 (\text{EI}_{i, \text{idle}}) + 0.0912 (\text{EI}_{i, \text{approach}}) + 0.1487 (\text{EI}_{i, \text{climb}}) \\ & + 0.0571 (\text{EI}_{i, \text{take-off}}) \end{aligned} \quad (4)$$

Alternately, equation (2) can be expressed as

$$\text{EPAP}_i = (\text{EPAP}_{i, \text{std}}) \left[\frac{\text{EI}_{ij}}{\text{EPAP}_{i, \text{std}} C_j} \right] \quad (5)$$

where $(\text{EPAP}_{i, \text{std}})$ is the standard for each type of emissions. For the CF6-50C, equation (5) becomes

$$\begin{aligned} \text{EPAP}_{\text{CO}} = & 4.3 \left[\frac{\text{EI}_{\text{CO, idle}}}{31.49} + \frac{\text{EI}_{\text{CO, approach}}}{47.15} + \frac{\text{EI}_{\text{CO, climb}}}{28.91} \right] \\ & + \frac{\text{EI}_{\text{CO, take-off}}}{75.30} \end{aligned} \quad (6a)$$

$$\begin{aligned} \text{EPAP}_{\text{HC}} = & 0.8 \left[\frac{\text{EI}_{\text{HC, idle}}}{5.859} + \frac{\text{EI}_{\text{HC, approach}}}{8.771} + \frac{\text{EI}_{\text{HC, climb}}}{5.379} \right] \\ & + \frac{\text{EI}_{\text{HC, take-off}}}{14.01} \end{aligned} \quad (6b)$$

$$\begin{aligned}
 \text{EPAP}_{\text{NO}_x} = 3.0 & \left[\frac{\text{EI}_{\text{NO}_x, \text{idle}}}{21.97} + \frac{\text{EI}_{\text{NO}_x, \text{approach}}}{32.89} + \frac{\text{EI}_{\text{NO}_x, \text{climb}}}{20.17} \right. \\
 & \left. + \left(\frac{\text{EI}_{\text{NO}_x, \text{take-off}}}{52.53} \right) \right] \quad (6c)
 \end{aligned}$$

In this form, each term in the summations is the fraction of the standard produced at that operating mode. Calculations based on equation (6) and measured emission indices are used to calculate the EPAP.

Production engine CF6-50 standard day dry EPAP values and the engine mode pollutant contributions to the valves are presented in table XV.

Pratt & Whitney EPAP calculations. - Production engine JT9D-7 standard day status cycle data are presented in table XVI. The NO_x , CO, and THC data were obtained from an 18-engine pilot lot data base with JP4 and Jet A fuel. Multiplication of the emission index for CO, THC, and NO_x by the EPAP coefficient at each engine mode yields the EPAP contribution for that engine mode. A summation of the EPAP contributions gives the EPAP value.

Current production JT9D-7 emission index values and EPAP values are contained in table XVII.

Report EPAP calculations. - All of the EPAP data contained in this report were computed using the methods and coefficients described above. Where combustion efficiencies were less than values assumed for the EPAP coefficient calculation, coefficient terms were not re-calculated.

RESULTS AND DISCUSSION

Presented in this section are summaries of pollution and performance test rig results for the combustor concepts evaluated in Phase II.

Pratt & Whitney Combustor Concepts

Since the Pratt & Whitney Phase II test program is still in progress, final

assessments regarding the combustors cannot be made at this time. Results obtained to date are given below.

Pollution results. - Total unburned hydrocarbon goals were achieved with both the vorbix and hybrid combustors. Carbon monoxide and oxides of nitrogen goal values were not achieved. However, substantial reductions of both pollutants, compared to reference JT9D-7 engine levels, were realized and program goals and 1979 EPA standards were approached. Smoke levels were low for both combustors.

Vorbix Combustor: Vorbix combustor test results, for all configurations evaluated, are contained in appendix B. A summary of these results is contained in table XVIII. Listed are the EPAP values including the EPAP contribution at each engine operating mode extrapolated to engine conditions, the 1979 EPAP standard values, and production JT9D-7 engine pollution levels. Three sets of test point combinations are presented for each configuration; those producing the lowest NO_x EPAP, those producing the lowest CO and THC EPAPS and those producing the lowest combined EPAP's for all three pollutants. Data points are identified by configuration numbers which are defined in the appendix.

The greatest single factor limiting achievable pollutant reductions with the vorbix combustor is CO formation in the pilot burner. This is especially true at the engine idle condition where program CO goal values were not achieved. At higher power points, NO_x reductions were also limited by pilot burner performance. In order to obtain high-combustion efficiencies, the pilot burner required a greater percentage of fuel than was desirable for low NO_x formation.

The vorbix combustor did demonstrate one operational feature which was not demonstrated by any other Phase II combustor. That is, at the approach condition, high-combustion efficiency performance was obtained with both the pilot and main burners fully fueled. This feature eliminates unnecessary fuel staging and should make achievement of required acceleration/deceleration performance easier to attain.

The best vorbix combustion pollution data were achieved with configurations S-11 and S-20. These results are contained in table XIX. Configuration S-11 produced the lowest NO_x , THC, and bled idle CO EPAP values. Configuration S-20 produced the lowest CO EPAP value but at the unbled idle condition. The unbled idle condition, at which the production JT9D-7 is evaluated, is less severe than the bled condition since combustor inlet temperatures and pressures are higher. Thus it appears that configuration S-11, although it was

not evaluated at the unbled idle condition, should be capable of producing the best vorbix pollution results.

Also included in table XIX are simulated cruise performance data. S-11 cruise results are not representative of attainable vorbix cruise pollution levels since the data were obtained at a non-optimum pilot-to-main burner fuel split. Configuration S-20 is more indicative of achievable cruise pollution levels. Two sets of cruise data are presented. They differ in that different amounts of fuel were supplied to the pilot burner. The higher CO, lower NO_x values were obtained with a smaller amount of fuel supplied to the pilot burner and a greater amount supplied to the main burner.

Hybrid Combustor: Hybrid combustor test results are contained in appendix C. A summary of test results is contained in table XX.

Major factors limiting the pollutant reductions which could be achieved with the hybrid combustor are the narrow combustion stability range of the pre-mix pilot burner and the quick quench of the main burner. The pilot burner, while producing excellent idle performance, did not operate efficiently at reduced pilot fuel-air ratios for higher engine power points when both burners were fired. In addition, at the approach condition, efficient combustion was not achievable with both burners fired, although efficient approach burning was achieved with only the pilot burner fired.

The best hybrid combustor pollution data were achieved with configurations H-5 and H-6. These data are contained in table XXI. Configuration H-5 produced the lowest NO_x EPAP value. Configuration H-6 produced the lowest CO and THC values.

Combustor performance results. - In most cases the vorbix combustor produced better performance results. The vorbix combustor demonstrated test rig relight capability comparable to the reference JT9D-7 engine-combustor. The hybrid combustor altitude relight was unsatisfactory with blowout and maximum relight occurring below required values.

Both combustor concepts produced pressure loss levels comparable to the reference combustor. Both combustors also produced radial average exit temperature profiles which, while not identical to the reference combustor profile, indicated that the reference combustor profile was achievable with additional effort.

Pattern factors measured for both combustor concepts at high-power conditions were higher than the reference combustor being 0.4 to 0.7 as compared to 0.42 for the reference combustor. However, it appears that with sufficient

added effort pattern factors for both concepts could be reduced to acceptable levels. At low-power conditions, vorbix combustor pattern factors were acceptable. Hybrid values were not, generally being greater than 1. While uneven temperature distributions are not generally a problem at low power conditions, gross maldistributions could have an effect on turbine life.

While combustor durability was not extensively investigated, potential durability problems appear to exist in both combustor concepts. The hybrid combustor pilot experienced flashback into the premix passage and some erosion occurred in the main stage swirlers. The vorbix combustor "throat" which joins the pilot and main burners appears to be particularly susceptible to hot spots and will require additional coolant air in the engine-combustor design.

Pollution and performance combustor assessments. - Based on the pollution and performance data obtained to date, the vorbix combustor was selected as the more promising concept and the one most readily adaptable to engine installation. Thus further Phase II testing will be restricted to the vorbix combustor and engine-combustor hardware will be designed and fabricated for Phase III engine testing.

Remaining Phase II testing will emphasize optimization of pollution reduction features, pattern factor and radial exit temperature tailoring, and further altitude relight assessments.

General Electric Combustor Concepts

The General Electric Phase II test program has been completed and the results obtained are given in the succeeding sections.

Pollution results. - Carbon monoxide and total unburned hydrocarbon goals were achieved with several of the GE combustors. Oxides of nitrogen goal values were not achieved. However, substantial NO_x reductions, compared to reference CF6-50 engine levels, were realized. Smoke levels were low for all combustor configurations investigated.

Double/Annular Combustor: Double/annular combustor results for all configurations are contained in appendix D. A summary of these results is contained in table XXII. As can be seen, 1979 required EPAP values for CO and THC were achieved and surpassed for all of the latter configurations. However, it was not possible to operate this combustor at approach conditions with both burning zones fully fueled.

The best double/annular pollution data obtained are shown in table XXIII. Configuration D/A-13 produced the lowest EPAP values for all pollutants. Two sets of EPAP values are shown. These include two different fueling modes at approach; the pilot only fueled and the pilot and one-half the main burner sector fueled. The pilot only mode produced the lowest CO and THC EPAP values. The pilot and one-half the main sector fueled produced a lower NO_x EPAP while still exceeding CO and THC EPAP requirements. Of the two modes, the pilot and one-half main fueling mode appears preferable since this mode will facilitate engine acceleration.

Configuration D/A-13 utilized all available combustor airflow for combustion and dilution, leaving none for tailoring of exit temperature distribution. Configuration D/A-10 has approximately 5 percent of the combustor airflow available for exit temperature and thus would probably be a more realistic configuration for engine installation. This configuration produced lower CO and THC EPAPs but a higher NO_x EPAP.

Although NO_x 1979 EPAP standard values were not achieved with the double/annular combustor, values of 4 to 4.5 have been achieved. These values represent substantial reductions compared to the reference CF6-50 engine value of 7.7. The NO_x EPAP requirement is particularly difficult to attain with the CF6-50 combustor because of its high pressure ratio of 30:1. The high-pressure ratio results in high combustor inlet temperatures and pressures both of which increase NO_x formation. The magnitude of these effects can be estimated by consideration of the NO_x correlation parameter described in a prior section.

Radial/Axial Combustor: Combustion and pollution results for all radial/axial combustor configurations are contained in appendix E. A summary of pollution results are contained in table XXIV. As can be seen, it was not possible to operate with high combustion efficiency at the approach condition with both burning zones fueled. Only the unburned hydrocarbon 1979 EPAP standard was achieved with this combustor. Decreases in NO_x levels were generally accompanied by increases in CO.

The best radial axial combustor pollution data were obtained with configuration R/A-2 and are given in table XXV. Two sets of data at climbout and take-off are included. These represent different pilot fuel-air ratios for the same overall fuel-air ratio. Reducing pilot fuel-air ratio typically produces lower NO_x EPAP values but accompanying higher THC and CO values. Cruise data for two different fueling modes are also included. By fueling only one-half the main

burner, NO_x EPAP values can be reduced by 1.5 without significantly affecting CO and THC emissions.

Combustor performance results. - Both the double/annular and the radial/axial combustor demonstrated pressure loss levels comparable to the reference CF6-50 combustor. Both combustors produced radial average exit temperature profiles which, while requiring additional tailoring to achieve reference values, indicated that reference values were achievable. Both combustors also demonstrated good altitude relight, cross-fire, and blowout capability. Relight assessments were made in a 60° sector rig and relight improvements were incorporated into the full-annular hardware as testing progressed.

Extensive carboning-durability assessments were made in another sector rig. Tests were conducted with heavy distillate fuels at increased pressures. Results indicated that the double/annular combustor does not appear to have any durability-carboning problems. The radial axial combustor, conversely, experienced upstream burning in the main stage premix passage with resulting hardware damage.

Pattern factors for both combustors were higher than desirable. At high-power conditions, pattern factors typically were between 0.35 to 0.50 as compared to the reference combustor value of 0.25. Double/annular pattern factors at low-power conditions of idle and approach were high - generally near 1. Thus additional efforts are required to reduce pattern factor values, especially for the double/annular combustor at low-power conditions. These efforts will be conducted in the early phases of the Phase III program where the engine-combustor hardware will be evaluated in the full-annular test facility prior to engine installation.

Pollution and performance combustor assessments. - Based on the Phase II pollution and performance data, the double/annular combustor was selected as the most promising concept and the one most readily adaptable to engine installation. This combustor concept has been designed and will be fabricated for Phase III engine testing.

PHASE III - ENGINE DEMONSTRATIONS

Up to the present, all testing conducted under the "Experimental Clean Combustor Program" has been in test rigs at reduced pressure conditions. It appears that two promising low-pollution combustor designs, the GE double/annular design

and the Pratt & Whitney vorbix design, suitable for engine installation have been developed. However, verification of the pollution reductions achieved as well as the practicality of the designs await the engine demonstration tests wherein the low-pollution combustors will be evaluated as components of the CF6-50 and JT9E-7 engines.

To date, the Phase III effort has been initiated and the engine demonstrations will be completed in 1976. The Phase III program consists of several efforts. These are described in succeeding sections.

Design Efforts

Design of combustor hardware was initiated in Phase II with final completion and solution of engine-combustor interface problems occurring in Phase III.

In addition to combustor hardware, engine fuel control systems capable of providing fuel distribution for multi-burning zone combustors are also being designed. The fuel control must satisfy all engine fuel handling requirements including acceleration, safety, and draining requirements. The control will be a breadboard design which will not include control of vane or bleed scheduling.

Engine Tests

A series of three test sequences will be conducted. These consist of the following:

Shakedown tests. - The purpose of the shakedown tests is to determine that the engine, combustor, and instrumentation are in proper working order for subsequent testing. In addition assessments will be made regarding fuel flow splits and their effect on engine acceleration. Testing will be primarily at idle and sub-idle power levels.

Steady-state performance/emissions tests. - The engines shall undergo a series of tests at actual engine operating conditions. Test objectives consist of the following:

1. Optimization and combination of engine/combustor hardware and fuel splits between burning zones.
2. Documentation of pollution and performance characteristics.
3. Assessments of pollution sampling techniques.

Data will be obtained at the engine power points listed in table XXVI. Two types of engine test points are indicated. Test points of primary interest are designated as main power points and consist of idle, approach, climbout, and take-off. Three fuel flow splits shall be investigated for each of these power settings. Variations in fuel flow splits will be utilized in assessing tradeoffs between combustion efficiency and emission levels.

In addition to the main power points, pollution and performance data will also be obtained at the six secondary power points listed in table XXVI. Data obtained at the secondary power points will be utilized to better establish engine pollution and performance characteristics.

Three techniques will be utilized to obtain engine exhaust pollution data. Implementation of these techniques is shown in table XXVI and is discussed below:

12-Point Fixed Sampling: The first technique will utilize the 12-point cruciform rake described in the Federal Register of July 17, 1973, volume 38, number 136 - Part II entitled "Control of Air Pollution from Aircraft and Aircraft Engines". This technique will be used at the main engine power points at the optimum fuel splits.

24-Point Fixed Sampling: The second technique also consists of fixed sampling and is the primary pollution sampling technique. It shall be utilized for all test points. This technique also consists of a cruciform rake with double the number of arms, 8 instead of 4. The arms will be located 45° apart with each arm containing three probe sampling positions at the centers of equal areas.

Traverse Sampling: Traverse sampling consists of rotating the probe described above and obtaining samples at 5° intervals. Traverse data will be obtained at the main engine power points at the optimum fuel splits.

Acceleration and deceleration tests. - Acceleration/deceleration engine tests will be made with several pilot to main burner fuel splits. The cut-in point of the main burner, once the engine has been started with the pilot burner, will also be investigated. Testing will be compatible with the design and construction requirements for transient engine operation as set forth in the Code of Federal Regulations of January 1, 1974, Subpart E, paragraph 33.73, "Power or Thrust Response". The 5-second power or thrust response, stated in the reference is considered a goal for engine acceleration rate. Acceleration testing will proceed as a series of progressively more rapid accelerations, starting from a relatively gradual rate and approaching the goal "snap acceleration" rate.

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APPENDIX A

This appendix contains description of combustor configurations evaluated in Phase II of the Experimental Clean Combustor program. Only the configurations evaluated for pollution reduction are described. Not contained are configurations evaluated for diffuser performance, altitude relight, and carboning-durability performance. These will be contained in subsequent contractor and NASA reports.

Vorbix Configurations

Pratt & Whitney evaluated 11 vorbix combustor configurations to date. The baseline design is shown in figure 6. Configurations are described in table A-I. Airflow splits are contained in table A-II.

Hybrid Configurations

Seven hybrid combustor configurations have been evaluated by Pratt & Whitney. The baseline design is shown in figure 7. Configuration descriptions are contained in table A-III. Airflow splits are contained in table A-IV.

Double/Annular Configurations

General Electric evaluated 14 double/annular combustor configurations. The baseline design is shown in figure 9. Configuration descriptions are contained in table A-V. Airflow splits are contained in table A-VI.

Radial/Axial Configurations

Seven radial/axial combustor configurations have been evaluated by General Electric. The baseline design is shown in figure 10. Configuration descriptions are contained in table A-VII. Airflow splits are contained in table A-VIII.

TABLE A-I. - PHASE II VORRIX COMBUSTOR CONFIGURATIONS, PRATT & WHITNEY

| CONFIG. NO. | MODIFICATIONS | DESIGN INTENT |
|---|--|--|
| S-11 | <p>BASELINE DESIGN: REFERENCED TO PHASE I CONFIGURATION S-10</p> <ol style="list-style-type: none"> 1. Throat annular height reduced. 2. Increased pilot burner volume - axial length increased 3.8 cm. 3. Reduce main burner cross-sectional area. 4. Add cooling air scoops to throat; incorporate improved main burner nozzle seating arrangement to eliminate liner-nozzle interference. | <ol style="list-style-type: none"> 1. Provide better separation between burning zones. 2. Contain idle burning in pilot. 3. Reduce main burner residence time. 4. Durability improvements. |
| S-12,13 | <ol style="list-style-type: none"> 1. Install alternating right and left hand main burner swirlers. 2. Configuration S-13 - Utilize 7 (alternate) instead of 13 main burner fuel injectors. | <ol style="list-style-type: none"> 1. Enhance main burner quick mixing. 2. Improve part power combustion efficiency. |
| S-14,15 | <ol style="list-style-type: none"> 1. Install low pressure drop fuel injectors in main burner. 2. Configuration S-15 - Utilize 7 (alternate) instead of 13 main burner fuel injectors. | <ol style="list-style-type: none"> 1. Optimize fuel injection system. 2. Improve part power combustion efficiency. |
| S-16 | <ol style="list-style-type: none"> 1. Add blockage rings to pilot swirlers. 2. Dilution air added downstream of main burner swirlers. 3. Install co-rotational swirlers in main burner. | <ol style="list-style-type: none"> 1. Optimize idle performance at design point fuel-air ratio. 2. Improve part power combustion efficiency. 3. Reduce quick quenching in main burner. |
| S-17 | Install aerating pilot nozzles in pilot fuel injectors. | Fuel injection study. |
| S-18 | Pilot burner redesigned with increased volume. S-17 aerating pilot nozzles retained. | Increase pilot zone residence time. |
| S-19 | Install pressure atomizing pilot nozzles. | Improve idle performance. |
| S-20 | Increase pilot airflow so equivalence ratio is 0.8. | Reduce equilibrium CO values. |
| S-21 | Main burner fuel injection system redesigned. Premix passages provided. | Reduce NOx formation through premixed fuel preparation. |
| PHASE II VORRIX TESTING STILL IN PROGRESS | | |

TABLE A-II. - VORBIX BURNER AIRFLOW SPLITS

| Location | S-11 | S-12 | S-13 | S-14 | S-15 | S-16 | S-17 | S-18 | S-19 | S-20 |
|--------------------|--------|-------|-------|-------|-------|-------|-------|-------|------|------|
| Pilot Nozzle | | | | | | | 3.16 | 5.68 | | |
| Pilot Swirler (SW) | 13.32 | 13.37 | 13.37 | 13.37 | 13.37 | 1.94 | 2.15 | 5.68 | 4.0 | 14.1 |
| Pilot SW Cool | 1.208 | 1.21 | 1.21 | 1.21 | 1.21 | 1.25 | 1.39 | | | |
| Main SW ID | 25.91 | 28.23 | 28.23 | 28.23 | 28.23 | 24.08 | 28.06 | 60.12 | 62.0 | 50.9 |
| Main SW OD | 28.88 | 26.17 | 26.17 | 26.17 | 26.17 | 31.53 | 28.85 | | | |
| ID D11 | | | | | | 4.05 | 4.01 | 3.21 | 3.0 | 4.0 |
| OD D11 | | | | | | 4.71 | 4.54 | 3.35 | 3.0 | 3.9 |
| Main Nozzle Cool | | 0.95 | 0.95 | 0.95 | 0.95 | 1.14 | 1.05 | 1.14 | 1.0 | 1.2 |
| Bulkhead Cool | 2.688 | 2.69 | 2.69 | 2.69 | 2.69 | 2.78 | 3.09 | 2.53 | 3.0 | 2.8 |
| Finwall Cyl | 2.658 | 2.29 | 2.29 | 2.29 | 2.29 | 2.23 | 2.54 | | | |
| Finwall ID | 1.249 | 1.08 | 1.08 | 1.08 | 1.08 | 1.05 | 1.19 | | | |
| Finwall OD | 1.344 | 1.14 | 1.14 | 1.14 | 1.14 | 1.38 | 1.37 | | | |
| ID Cool | 6.655 | 7.76 | 7.76 | 7.76 | 7.76 | 7.37 | 7.94 | 8.79 | 8.0 | 7.6 |
| OD Cool | 10.556 | 9.70 | 9.70 | 9.70 | 9.70 | 10.86 | 4.92 | 10.26 | 1.0 | 10.8 |
| Sidewall Cool | 4.914 | 5.40 | 5.40 | 5.40 | 5.40 | 5.62 | 5.75 | 4.94 | 5.0 | 4.8 |

TABLE A-III. - PHASE II HYBRID COMBUSTOR CONFIGURATIONS, PRATT & WHITNEY

| CONFIG. NO. | MODIFICATIONS | DESIGN INTENT |
|---|---|---|
| | BASELINE DESIGN: REFERENCED TO PHASE I PREMIX AND SWIRL-CAN CONFIGURATIONS | |
| H-1 | <ol style="list-style-type: none"> 1. Premixed pilot from Phase I configuration P-3. 2. Swirl-can main burner with outer swirler flameholders and fuel splashplate. 3. Main burner diffuser inserts. | Combine two Phase I combustor concepts: low idle pollutants with the premix pilot burner; low NOx production with the swirl-can main burner. |
| H-2 | Install counter rotating inner and outer main burner swirlers | Enhance mixing and reduce NOx. |
| H-3 | <ol style="list-style-type: none"> 1. Block outer flow path on main burner and add dilution air on the o.d. 2. Provide staged main burner fuel system. | <ol style="list-style-type: none"> 1. Reduce main burner residence time by quick quench. 2. Investigate staging of fuel at part power points. |
| H-4 | Install pilot spray cone pilot fuel nozzles. | Fuel injection study. |
| H-5 | <ol style="list-style-type: none"> 1. Install configuration H-1 with reduced pilot premix passage airflow. 2. Increase current dilution airflow levels. | <ol style="list-style-type: none"> 1. Permit operation at part and high power with reduced required pilot fuel flow. 2. Maintain pressure drop. |
| H-6 | Pilot dilution air eliminated and flow diverted to pilot premix passage and main burner bulkhead. | Permit part and high power operation with reduced pilot fuel flow; eliminate quick-quench effects. |
| H-7 | Install configuration H-6 with solid cone pilot nozzles | Fuel injection study. |
| HYBRID TEST PROGRAM STOPPED AFTER CONFIGURATION H-7 | | |

TABLE A-IV. - HYBRID BURNER AIRFLOW SPLITS

| Location | H-1 | H-2 | H-3 | H-4 | H-5 | H-6 | H-7 |
|-------------------------|-------|-------|-------|-------|-------|-------|-------|
| Pilot F.H. | 18.14 | 16.30 | 18.0 | 18.0 | 12.46 | 12.46 | 12.46 |
| Pilot F.H. Weep | 4.85 | 4.40 | 4.0 | 4.0 | 3.51 | 3.51 | 3.51 |
| Pilot F.H. Cool (I. D.) | ----- | ----- | 0.6 | 0.6 | 0.47 | 0.47 | 0.47 |
| Main outer Sw. | 24.00 | 24.50 | ----- | ----- | 34.16 | 34.16 | 34.16 |
| Main inner Sw. | 20.34 | 20.80 | 15.8 | 15.8 | 18.85 | 18.85 | 18.85 |
| Bulk. Cool | 3.94 | 4.00 | 4.4 | 4.4 | 3.87 | 3.87 | 3.87 |
| Dilution I. D. | 10.64 | 11.00 | 12.7 | 12.7 | 9.83 | 9.83 | 9.83 |
| Dilution O. D. (1) | ----- | ----- | 15.7 | 15.7 | ----- | ----- | ----- |
| Dilution O. D. (2) | ----- | ----- | 9.2 | 9.2 | ----- | ----- | ----- |
| Finwall (I. D.) | 0.82 | 0.82 | 1.0 | 1.0 | 0.73 | 0.73 | 0.73 |
| Finwall (O. D.) | 0.99 | 1.00 | 1.3 | 1.3 | 0.89 | 0.89 | 0.89 |
| I. D. Cool | 4.88 | 5.00 | 6.1 | 6.1 | 4.50 | 4.50 | 4.50 |
| O. D. Cool | 6.30 | 6.90 | 5.6 | 5.6 | 5.99 | 5.99 | 5.99 |
| Side wall | 5.1 | 5.40 | 5.5 | 5.5 | 4.72 | 4.72 | 4.72 |

TABLE A-V. - PHASE II DOUBLE/ANNULAR COMBUSTOR CONFIGURATION, GENERAL ELECTRIC

| CONFIG. NO. | MODIFICATIONS | DESIGN INTENT |
|----------------|---|--|
| | REFERENCED TO PHASE I BASELINE DESIGN D/A -II-16 | |
| D/A-1 | <ol style="list-style-type: none"> Centerbody extended 3.17 cm. Install pilot swirlers from Phase I configuration III-2. Provide main burner dome dilution holes: 60 @ 0.95 cm diameter | <ol style="list-style-type: none"> Provide better sheltering for idle burning. Best available from Phase I. Provide leaner main burning; approach design pressure loss. |
| D/A-2 | <ol style="list-style-type: none"> Install stronger pilot secondary swirlers. Add mixing section (barrels) to main burner swirlers. Move main burner dome aft 1.45 cm. | <ol style="list-style-type: none"> Improve pilot fuel-air atomization and mixing. Improve fuel-air mixing. Accommodate No. 2; reduce dome to dilution length 20%. |
| D/A-3 | <ol style="list-style-type: none"> Install higher flow primary and secondary air swirlers on main burner. Centerbody shortened to original length. Remove liner air dilution holes. | <ol style="list-style-type: none"> 1,2. Provide leaner main burner mixture and burning. 3. Provide leaner main burner; improve idle performance. |
| D/A-4 | <ol style="list-style-type: none"> Install new pilot burner nozzle-swirler assembly - 60° axial secondary swirlers, 90° simplex nozzles. Reduce pilot burner liner coolant 33%. Modify main burner nozzle swirler - primary swirler immersion decreased from .89 to .13 cm; pressure atomizing fuel nozzles installed. | <ol style="list-style-type: none"> Provide increased pilot burner cup air-fuel mixing. Eliminate excess coolant. Increase mixing within swirl-cup. |
| D/A-5 | <ol style="list-style-type: none"> Add barrel extensions to pilot burner swirlers. Pilot burner dome and centerbody moved downstream 1.8 cm. | <ol style="list-style-type: none"> Promote mixing. Accommodate modification no. 1. |
| D/A-6 | <ol style="list-style-type: none"> Add 120- .056 cm dia. dilution holes to first pilot burner liner panel. Close main burner dilution holes, put air through first liner panel. | <ol style="list-style-type: none"> Produce more favorable stoichiometry - reduce idle pollutants. Promote more effective mixing for NOx reduction. |
| D/A-7 | <ol style="list-style-type: none"> Enlarge pilot burner liner dilution holes Primary and secondary swirlers from D/A-1,2 installed in main burner and liner dilution holes enlarged. Centerbody slotted in one location (3.8 long by 2.5 cm wide). | <ol style="list-style-type: none"> Optimize pilot design - reduce NO emissions. Improve main burner stability. Improve cross-fire characteristics. |
| D/A-8 | <ol style="list-style-type: none"> Pilot burner dilution holes moved from first to second liner panel. Main burner dilution holes moved to fourth liner panel Install lower flow rate simplex fuel nozzles. Pilot burner nozzles reduced from 20 to 17 kg/hr; main burner nozzles reduced from 50 to 20 kg/hr. | <ol style="list-style-type: none"> Reduce idle emissions. Achieve better combustor mechanical design Permit more variability in fuel staging. |
| D/A-9 | <ol style="list-style-type: none"> Main burner fourth panel dilution holes closed, first panel holes enlarged. | <ol style="list-style-type: none"> Produce more rapid main burner quenching. |
| D/A-10 | D/A-7 main burner configuration rebuilt. | Determine if low NOx emissions of D/A-7 can be reproduced. |
| D/A-11 | <ol style="list-style-type: none"> Main burner dilution holes moved to fourth liner panel. On main burner, move 30 dilution holes located between swirl cups from first panel to second panel. | <ol style="list-style-type: none"> Develop better combustor mechanical design. Promote more effective mixing, evolve better mechanical design. |

TABLE A-V. - DOUBLE/ANNULAR COMBUSTOR CONFIGURATIONS cont.

| CONFIG. NO. | MODIFICATIONS | DESIGN INTENT |
|--|--|--|
| D/A-12 | <ol style="list-style-type: none"> 1. Main stage second panel dilution holes moved back to first panel 2. New pilot burner primary swirler/venturi installed 3. Pilot burner secondary swirler flow area reduced by 17%. 4. New pilot burner fuel nozzles installed | <ol style="list-style-type: none"> 1. Second liner panel location produced higher NOx levels. 2. Design passed carboning tests and met altitude relight requirements. 3. Design matches flow area of the Phase III engine-combustor design. 4. Design matches Phase III engine-combustor design. |
| D/A-13 | <ol style="list-style-type: none"> 1. Main burner aft profile trim holes in 4th liner panel closed and first liner panel dilution holes enlarged. 2. Thimbles added to main burner first panel dilution holes to increase diluent penetration. | <ol style="list-style-type: none"> 1,2. Obtain lower NOx values by better mixing, quenching and leaner burning. |
| D/A-14 | <ol style="list-style-type: none"> 1. Main burner 4th panel liner trim holes opened. 2. Main burner liner thimbles removed. 3. Pilot burner liner dilution hole diameter increased from .67 cm to .71 cm. 4. Pilot burner liner first panel coolant increased from 0.9 to 2.8 %. | <ol style="list-style-type: none"> 1. Provide more open area and lower pressure loss. 2. Not practical for engine installation. 3. Simulate cooling airflow distribution of the Phase III engine-combustor. 4. Simulate Phase III engine-combustor design. |
| D/A-14b | Engine prototype fuel nozzles installed on pilot burner stage. | Simulate engine-combustor design. |
| DOUBLE/ANNULAR TEST PROGRAM COMPLETED FOR PHASE II | | |

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TABLE A-VI. - AIRFLOW DISTRIBUTIONS, ALL DOUBLE/ANNULAR COMBUSTOR CONFIGURATIONS

| CONFIGURATION | II-4 | II-8 | II-9 | II-11 | II-13 | II-16 | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 | D11 | D12 | D13 | D14 | Engine Design |
|----------------------|------|------|------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|-------|------|---------------|
| OUTER SWIRL CUPS | | | | | | | | | | | | | | | | | | | | | |
| Fuel Nozzle Shroud | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.9 | 0.1 | 0.8 | 0.8 |
| Primary Swirler | 3.4 | 3.4 | 3.4 | 3.4 | 3.6 | 4.0 | 3.5 | 3.6 | 3.6 | 3.7 | 3.6 | 3.5 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 5.2 | 5.1 | 4.7 | 4.6 |
| Secondary Swirler | 28.4 | 14.1 | 14.1 | 14.1 | 13.5 | 7.3 | 8.8 | 7.1 | 7.2 | 9.0 | 9.0 | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 | 7.4 | 7.3 | 6.7 | 7.2 |
| Total | 32.7 | 18.4 | 18.4 | 18.4 | 18.0 | 12.2 | 13.2 | 11.6 | 11.7 | 12.8 | 12.7 | 12.4 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 13.4 | 12.5 | 12.2 | 12.6 |
| INNER SWIRL CUPS | | | | | | | | | | | | | | | | | | | | | |
| Fuel Nozzle Shroud | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 1.5 |
| Primary Swirler | 3.4 | 3.4 | 3.4 | 3.4 | 3.6 | 4.0 | 3.5 | 3.6 | 9.5 | 9.6 | 9.6 | 9.3 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.5 | 3.5 | 3.2 | 4.6 |
| Secondary Swirler | 28.4 | 14.1 | 28.7 | 28.7 | 30.0 | 32.1 | 29.1 | 29.6 | 38.3 | 39.0 | 38.6 | 37.6 | 29.8 | 29.8 | 29.6 | 29.8 | 29.7 | 29.5 | 29.3 | 27.0 | 26.9 |
| Total | 32.7 | 18.4 | 33.0 | 33.0 | 34.5 | 37.0 | 33.5 | 34.1 | 48.7 | 48.7 | 48.3 | 47.0 | 33.5 | 33.5 | 33.5 | 33.5 | 33.4 | 33.1 | 32.9 | 30.3 | 33.0 |
| DILUTION | | | | | | | | | | | | | | | | | | | | | |
| Outer Liner, Panel 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.2 | 4.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Outer Liner, Panel 2 | 0 | 14.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.6 | 4.9 | 4.5 |
| Inner Dome | 0 | 0 | 0 | 0 | 0 | 0 | 4.8 | 4.9 | 4.9 | 5.0 | 5.0 | 0 | 4.9 | 0 | 0 | 4.9 | 0 | 0 | 0 | 0 | 0 |
| Inner Liner, Panel 1 | 0 | 0 | 0 | 13.8 | 17.5* | 18.7* | 16.9* | 17.3* | 0 | 0 | 0 | 4.3 | 10.9 | 10.9 | 16.1 | 10.9 | 5.5 | 10.8 | 17.0* | 15.7 | 10.6 |
| Inner Liner, Panel 2 | 0 | 13.7 | 13.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.5 | 0 | 0 | 0 | 0 |
| Inner Liner, Panel 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.9 | 0 | 0 | 4.9 | 4.9 | 0 | 4.4 | 2.0 |
| Total | 0 | 28.6 | 13.8 | 13.8 | 17.5 | 18.7 | 21.7 | 22.2 | 4.9 | 5.0 | 5.0 | 7.5 | 20.5 | 20.5 | 20.8 | 20.5 | 20.6 | 20.4 | 21.6 | 25.1 | 17.1 |
| COOLING | | | | | | | | | | | | | | | | | | | | | |
| Outer Liner | 11.2 | 11.2 | 11.2 | 11.2 | 8.0 | 8.5 | 7.7 | 7.9 | 7.6 | 7.5 | 8.2 | 8.0 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.0 | 8.0 | 9.4 | 9.4 |
| Outer Dome | 4.2 | 4.2 | 4.2 | 4.2 | 4.4 | 4.7 | 5.1 | 5.3 | 5.3 | 4.6 | 4.6 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.4 | 4.1 | 7.1 |
| Centerbody | 3.1 | 3.1 | 3.1 | 3.1 | 3.3 | 3.6 | 3.9 | 3.9 | 4.0 | 4.1 | 4.0 | 3.9 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.9 | 3.9 | 3.6 | 3.1 |
| Inner Dome | 3.9 | 3.9 | 3.9 | 3.9 | 4.1 | 4.3 | 5.0 | 4.9 | 4.9 | 4.2 | 4.2 | 4.1 | 4.1 | 4.1 | 4.0 | 4.1 | 4.1 | 4.1 | 4.1 | 3.7 | 5.3 |
| Inner Liner | 10.8 | 10.8 | 11.0 | 11.0 | 8.7 | 9.4 | 8.4 | 8.6 | 11.4 | 11.6 | 11.5 | 11.1 | 11.3 | 11.3 | 11.3 | 11.3 | 11.3 | 11.2 | 11.1 | 10.2 | 10.8 |
| Seal Leakage | 1.4 | 1.4 | 1.4 | 1.4 | 1.5 | 1.6 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.4 | 1.4 |
| Total | 34.6 | 34.6 | 34.8 | 34.8 | 30.0 | 32.1 | 31.6 | 32.1 | 34.7 | 33.5 | 34.0 | 33.1 | 33.5 | 33.5 | 33.4 | 33.5 | 33.5 | 33.2 | 33.0 | 32.4 | 37.3 |

* Thimble Dilution Holes

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TABLE A-VIII. - AIRFLOW DISTRIBUTIONS, RADIAL/AXIAL-STAGED COMBUSTOR

| | Configuration | | | | | | | Engine Design |
|-------------------------------------|---------------|-------------|------------|------------|-------------|-------------|-------------|---------------|
| | R1 | R2 | R3 | R4 | R5 | R6 | R7 | |
| Pilot Cups | | | | | | | | |
| Fuel Nozzle Shroud | 0.9 | 0.9 | 0.9 | 0.1 | 0.1 | 0.1 | 0.1 | 0.8 |
| Primary Swirler | 3.2 | 3.2 | 3.2 | 3.2 | 3.9 | 3.3 | 4.1 | 3.9 |
| Secondary Swirler | <u>5.4</u> | <u>8.0</u> | <u>7.9</u> | <u>7.9</u> | <u>11.1</u> | <u>9.5</u> | <u>11.5</u> | <u>7.5</u> |
| Total | 9.5 | 12.1 | 12.0 | 11.2 | 15.1 | 12.9 | 15.7 | 12.2 |
| Main Stage Flameholders | | | | | | | | |
| Carbureted | 63.9 | 16.9 | 65.1 | 65.6 | 47.0 | 17.7 | 47.2 | 50.0 |
| Uncarbureted | <u>0</u> | <u>47.5</u> | <u>0</u> | <u>0</u> | <u>0</u> | <u>40.8</u> | <u>0</u> | <u>0</u> |
| Total | 63.9 | 64.6 | 65.1 | 65.6 | 47.0 | 58.5 | 47.2 | 50.0 |
| Dilution | | | | | | | | |
| Pilot Stage | 0 | 0 | 0 | 0 | 0 | 4.5 | 5.5 | 4.5 |
| Inner Liner | <u>0</u> | <u>0</u> | <u>0</u> | <u>0</u> | <u>8.7</u> | <u>0</u> | <u>0</u> | <u>2.0*</u> |
| Total | 0 | 0 | 0 | 0 | 8.7 | 4.5 | 5.5 | 6.5 |
| Cooling | | | | | | | | |
| Pilot Stage | 11.1 | 7.6 | 7.5 | 7.6 | 9.3 | 7.9 | 11.4 | 11.1 |
| Flameholders | 1.3 | 1.3 | 1.1 | 1.1 | 1.5 | 1.1 | 1.7 | 1.4 |
| Outer Liner | 5.5 | 5.6 | 5.6 | 5.7 | 6.9 | 5.9 | 7.2 | 6.7 |
| Inner Liner | 7.4 | 7.5 | 7.4 | 7.5 | 9.2 | 7.8 | 9.6 | 10.7 |
| Seal Leakage | <u>1.3</u> | <u>1.3</u> | <u>1.3</u> | <u>1.3</u> | <u>1.6</u> | <u>1.4</u> | <u>1.7</u> | <u>1.4</u> |
| Total | 26.6 | 23.3 | 22.9 | 23.2 | 28.5 | 24.1 | 31.6 | 31.3 |
| * Aft dilution for profile trimming | | | | | | | | |

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APPENDIX B

This appendix contains summaries of test rig data for all of the Pratt & Whitney vortex combustor configurations evaluated in Phase II of the Experimental Clean Combustor Program. Data are presented in two groupings:

1. Test Rig Data - In this section, data are presented as they were obtained in the test rig with one exception. In setting test point conditions, it was rarely possible to operate precisely at the design point fuel-air ratio. Thus, when more than fuel-air ratio was investigated at a test condition, the general procedure used was to plot the emissions against fuel-air ratio and determine emission levels at the design point fuel-air ratio by interpolation. When only one fuel-air ratio was investigated at a test condition, emission levels at that value are reported.

2. Data Corrected to Engine Pressures - Correlations which were used to extrapolate test rig data to engine conditions are contained in the Data Correlation Procedures section of the report. Calculations of EPAP values were made according to the procedures described in the EPAP Calculations section of the report.

APPENDIX B-1

P & W VORBITZ COMBUSTOR DATA, CONFIGURATION S-11

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLEED | APPROACH | | CLIMBOUT | TAKE-OFF | | | | | | CRUISE | |
|-------------------------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--|
| READING NUMBER | I-1 | APP-1 | APP-2 | CLI-1 | TO.-1 | TO.-2 | TO.-3 | TO.-4 | TO.-5 | TO.-6 | CTOL CRUISE | |
| FUELING MODE | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.94 | 6.67 | 6.71 | 6.75 | 6.81 | 6.72 | 6.78 | 6.71 | 6.85 | 6.77 | 6.80 | |
| FUEL-AIR RATIO-PILOT | .0126 | .0074 | .0096 | .0042 | .0032 | .0036 | .0047 | .0056 | .0065 | .0072 | .0040 | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0139 | .0140 | .0208 | .0217 | .0193 | .0193 | .0215 | .0192 | .0216 | .0200 | |
| CO - E.I. | 36.0 | 26.0 | 14.2 | 25.0 | 11.2 | 33.6 | 11.9 | 7.8 | 5.3 | 7.0 | 38.9 | |
| THC - E.I. | 0.8 | 2.1 | 0.6 | 1.5 | 5.0 | 2.5 | 0.7 | -0- | 0.2 | 0.3 | 56.7 | |
| NO _x - E.I. | 4.1 | 5.3 | 7.1 | 8.5 | 9.9 | 8.5 | 9.2 | 10.1 | 9.2 | 10.3 | 5.7 | |
| SMOKE NO. | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |
| COMBUSTION EFFICIENCY % | 99.1 | 99.2 | 99.6 | 99.3 | 99.2 | 99.0 | 99.7 | 99.8 | 99.9 | 99.8 | 93.4 | |
| PATTERN FACTOR | 0.27 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |
| CO - EPAP CONTRIBUTION | 6.19 | 1.77 | 0.97 | 2.66 | 0.46 | 1.39 | 0.49 | 0.32 | 0.22 | 0.29 | --- | |
| THC - EPAP CONTRIBUTION | 0.14 | 0.14 | 0.04 | 0.16 | 0.21 | 0.10 | 0.01 | -0- | 0.01 | 0.01 | --- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | |
|--|------|------|------|------|------|------|------|------|------|------|------|--|
| CO - E.I. | 36.0 | 23.0 | 11.8 | 14.7 | 4.0 | 20.6 | 4.4 | 2.0 | 0.9 | 1.6 | 28.4 | |
| THC - E.I. | 0.8 | 1.7 | 0.5 | 0.6 | 1.6 | 0.8 | 0.1 | -0- | 0.1 | 0.1 | 40.9 | |
| NO _x - E.I. | 3.8 | 5.1 | 6.7 | 11.9 | 15.4 | 14.5 | 15.2 | 16.2 | 14.9 | 17.0 | 6.2 | |
| COMBUSTION EFFICIENCY % | 99.1 | 99.3 | 99.7 | 99.6 | 99.7 | 99.4 | 99.9 | 100 | 100 | 100 | 95.2 | |
| CO - EPAP CONTRIBUTION | 6.19 | 1.57 | 0.80 | 1.56 | 0.16 | 0.85 | 0.18 | 0.08 | 0.04 | 0.07 | --- | |
| THC - EPAP CONTRIBUTION | 0.14 | 0.11 | 0.03 | 0.06 | 0.07 | 0.03 | 0.04 | -0- | -0- | -0- | --- | |
| NO _x - EPAP CONTRIBUTION | 0.65 | 0.35 | 0.46 | 1.27 | 0.64 | 0.60 | 0.63 | 0.67 | 0.62 | 0.70 | --- | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX B-2

P & W VORBIK COMBUSTOR DATA, CONFIGURATIONS S-12,13

TEST RIG DATA

| ENGINE CONDITION | IDLE BIED | APPR. | CLIMBOUT | TAKE-OFF | | | | | | | NO CRUISE DATA |
|-------------------------------|---------------|---------------|---------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|----------------|
| READING NUMBER | I-1 | APP-1 | CLI-1 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | TO-6 | TO-7 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & 7 MAIN INJ. | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & 7/11 MAIN | PILOT & 7/11 MAIN | |
| INLET PRESSURE ATM. | 2.92 | 6.81 | 6.73 | 6.76 | 6.79 | 6.82 | 6.84 | 6.86 | 6.81 | 6.81 | |
| FUEL-AIR RATIO-PILOT | .0121 | .0130 | .0060 | .0036 | .0046 | .0050 | .0058 | .0073 | .0050 | .0088 | |
| FUEL-AIR RATIO-TOTAL | .0121 | .0130 | .0192 | .0216 | .0222 | .0215 | .0219 | .0222 | .0169 | .0221 | |
| CO - E.I. | 36.0 | 7.5 | 23.3 | 57.3 | 51.5 | 59.5 | 39.2 | 31.9 | 20.0 | 19.4 | |
| THC - E.I. | 1.9 | 0.4 | 0.9 | 3.8 | 1.4 | 1.3 | 1.1 | 0.8 | 0.9 | 0.5 | |
| NO _x - E.I. | 3.6 | 10.2 | 8.3 | 9.7 | 9.9 | 9.7 | 10.7 | 12.0 | 9.0 | 13.9 | |
| SMOKE NO. | ---- | ---- | 1. | 9. | ---- | 1. | ---- | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.0 | 99.8 | 99.4 | 98.3 | 98.7 | 98.5 | 99.0 | 99.2 | 99.4 | 99.5 | |
| PATTERN FACTOR | 0.46 | ---- | ---- | ---- | ---- | 0.49 | ---- | ---- | 0.49 | ---- | |
| CO - EPAP CONTRIBUTION | 6.19 | 0.51 | 2.48 | 2.37 | 2.13 | 2.46 | 1.62 | 1.32 | 0.83 | 0.80 | |
| THC - EPAP CONTRIBUTION | 0.33 | 0.03 | 0.10 | 0.16 | 0.06 | 0.05 | 0.05 | 0.03 | 0.04 | 0.02 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | |
|---|------|-------|------|------|------|------|------|------|------|------|--|
| CO - E.I. | 35.8 | 3.3 | 13.3 | 40.9 | 35.9 | 43.0 | 25.4 | 19.3 | 10.0 | 9.51 | |
| THC - E.I. | 1.9 | 0.3 | 0.3 | 1.2 | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 | 0.2 | |
| NO _x - E.I. | 3.2 | 9.4* | 12.3 | 15.5 | 15.4 | 15.0 | 16.7 | 18.3 | 15.7 | 21.4 | |
| COMBUSTION EFFICIENCY % | 99.0 | 99.9 | 99.7 | 98.9 | 99.1 | 99.0 | 99.4 | 99.5 | 99.7 | 99.8 | |
| CO - EPAP CONTRIBUTION | 6.16 | 0.23 | 1.42 | 1.69 | 1.49 | 1.78 | 1.05 | 0.80 | 0.41 | 0.39 | |
| THC - EPAP CONTRIBUTION | 0.33 | 0.02 | 0.04 | 0.05 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | |
| NO _x - EPAP CONTRIBUTION. | 0.55 | 0.64* | 1.31 | 0.64 | 0.64 | 0.62 | 0.69 | 0.76 | 0.65 | 0.89 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* --- P² NO_x EXTRAPOLATION TO ENGINE PRESSUREORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX B-3

P & W VORBITZ COMBUSTOR DATA, CONFIGURATIONS S-14, 15

1. TEST RIG DATA

| ENGINE CONDITION | SAME PILOT AS S-12,13 IDLE, APPROACH PILOT DATA SAME | NO CLIMB. DATA | TAKE-OFF | | | | | NO CRUI DATA |
|-------------------------------|---|-------------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|-----------------|
| READING NUMBER | | | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | |
| FUELING MODE | | | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & 7/11 MAIN | PILOT & 7/11 MAIN | |
| INLET PRESSURE ATM. | | | 6.71 | 6.81 | 6.75 | 6.76 | 6.76 | |
| FUEL-AIR RATIO-PILOT | | | .0042 | .0058 | .0090 | .0041 | .0058 | |
| FUEL-AIR RATIO-TOTAL | | | .0223 | .0219 | .0223 | .0220 | .0219 | |
| CO - E.I. | | | 17.6 | 15.2 | 15.0 | 71.9 | 61.9 | |
| THC - E.I. | | | 2.8 | 1.1 | 0.1 | 3.9 | 2.2 | |
| NO _x - E.I. | | | 12.5 | 13.7 | 18.5 | 8.7 | 10.2 | |
| SMOKE NO. | | | ----- | ----- | ----- | ----- | ----- | |
| COMBUSTION EFFICIENCY % | | | 98.6 | 99.5 | 99.6 | 97.9 | 98.4 | |
| PATTERN FACTOR | | | ----- | ----- | ----- | ----- | ----- | |
| CO - EPAP CONTRIBUTION | | | 1.97 | 0.63 | 0.62 | 2.98 | 2.53 | |
| THC - EPAP CONTRIBUTION | | | 0.12 | 0.01 | 0.01 | 0.16 | 0.09 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | | | 32.1 | 6.5 | 6.3 | 51.1 | 14.1 | |
|--|--|--|------|------|------|------|------|--|
| THC - E.I. | | | 0.9 | 0.1 | 0.1 | 1.3 | 0.7 | |
| NO _x - E.I. | | | 19.5 | 21.5 | 28.5 | 13.3 | 15.8 | |
| COMBUSTION EFFICIENCY % | | | 99.2 | 99.8 | 99.8 | 98.6 | 98.9 | |
| CO - EPAP CONTRIBUTION | | | 1.34 | 0.27 | 0.26 | 2.24 | 1.84 | |
| THC - EPAP CONTRIBUTION | | | 0.04 | 0.01 | 0.01 | 0.05 | 0.03 | |
| NO _x - EPAP CONTRIBUTION | | | 0.81 | 0.89 | 1.18 | 0.55 | 0.65 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX B-4

P & W VORBITZ COMBUSTOR DATA, CONFIGURATION S-16

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLEED | NO APPROACH DATA | NO CLIMBOUT DATA | TAKE-OFF | | | | | NO CRUISE DATA |
|-------------------------------|---------------|---------------------|---------------------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------|
| READING NUMBER | I-1 | | | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | |
| FUELING MODE | PILOT ONLY | | | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.93 | | | 6.67 | 6.77 | 6.84 | 6.73 | 6.66 | |
| FUEL-AIR RATIO-PILOT | .0126 | | | .0052 | .0056 | .0066 | .0075 | .0097 | |
| FUEL-AIR RATIO-TOTAL | .0126 | | | .0220 | .0162 | .0192 | .0224 | .0214 | |
| CO - E.I. | 61.5 | | | 26.4 | 10.6 | 13.0 | 22.6 | 8.7 | |
| THC - E.I. | 1.0 | | | 0.5 | 0.3 | -0- | 0.2 | -0- | |
| NO _x - E.I. | 3.3 | | | 10.9 | 12.1 | 14.0 | 14.6 | 13.6 | |
| SMOKE NO. | ---- | | | ---- | ---- | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 98.5 | | | 99.3 | 99.7 | 99.7 | 99.5 | 99.8 | |
| PATTERN FACTOR | 0.29 | | | ---- | 0.80 | ---- | ---- | ---- | |
| CO - EPAP CONTRIBUTION | 10.6 | | | 1.09 | 0.44 | 0.54 | 0.94 | 0.36 | |
| THC - EPAP CONTRIBUTION | 0.2 | | | 0.02 | 0.01 | -0- | 0.01 | -0- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | 61.5 | | | 11.7 | 3.6 | 5.1 | 11.8 | 2.4 | |
|---|------|--|--|------|------|------|------|------|--|
| THC - E.I. | 1.0 | | | 0.2 | 0.1 | -0- | 0.1 | -0- | |
| NO _x - E.I. | 3.0 | | | 17.4 | 21.5 | 22.8 | 22.7 | 22.4 | |
| COMBUSTION EFFICIENCY % | 98.5 | | | 99.6 | 99.9 | 99.9 | 99.7 | 99.9 | |
| CO - EPAP CONTRIBUTION | 10.6 | | | 0.61 | 0.15 | 0.21 | 0.49 | 0.10 | |
| THC - EPAP CONTRIBUTION | 0.17 | | | 0.01 | -0- | -0- | -0- | -0- | |
| NO _x - EPAP CONTRIBUTION. | 0.51 | | | 0.72 | 0.89 | 0.95 | 0.94 | 0.93 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX B-5

P & W VORLIX COMBUSTOR DATA, CONFIGURATION S-17

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | APPROACH | CLIMBOUT | TAKE-OFF | | | | | | NO CRUISE DATA |
|-------------------------------|---------------|---------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------|
| READING NUMBER | I-1 | APP-1 | CL-1 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | TO-6 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.93 | 6.80 | 6.71 | 6.78 | 6.82 | 6.75 | 6.81 | 6.84 | 6.80 | |
| FUEL-AIR RATIO-PILOT | .0126 | .0136 | .0198 | .0215 | .0022 | .0042 | .0054 | .0075 | .0098 | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0136 | .0198 | .0215 | .0220 | .0220 | .0217 | .0224 | .0217 | |
| CO - E.I. | 55.6 | 15.7 | 8.2 | 7.3 | 82.7 | 35.1 | 25.1 | 20.5 | 11.9 | |
| THC - E.I. | 1.3 | 0.4 | 0.4 | 0.6 | 10.9 | 1.1 | 0.7 | 0.5 | 0.2 | |
| NO _x - E.I. | 3.0 | 4.7 | 6.8 | 7.4 | 8.1 | 11.3 | 12.5 | 14.7 | 15.7 | |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 98.6 | 99.6 | 99.8 | 99.8 | 97.0 | 99.1 | 99.3 | 99.5 | 99.7 | |
| PATTERN FACTOR | 0.30 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| CO - EPAP CONTRIBUTION | 9.56 | 1.07 | 0.87 | 0.30 | 3.42 | 1.45 | 1.04 | 0.85 | 0.49 | |
| THC - EPAP CONTRIBUTION | 0.22 | 0.03 | 0.04 | 0.02 | 0.45 | 0.05 | 0.03 | 0.02 | 0.01 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | |
|--|------|-------|------|------|------|------|------|------|------|--|
| CO - E.I. | 55.5 | 9.5 | 0.3 | 0.1 | 63.9 | 21.8 | 13.9 | 10.4 | 4.4 | |
| THC - E.I. | 1.3 | 0.3 | 0.2 | 0.2 | 3.5 | 0.4 | 0.2 | 0.2 | 0.1 | |
| NO _x - E.I. | 2.5 | 4.3 | 10.3 | 11.7 | 12.8 | 18.0 | 19.6 | 22.4 | 24.4 | |
| COMBUSTION EFFICIENCY % | 98.6 | 99.8 | 100 | 100 | 98.2 | 99.5 | 99.7 | 99.7 | 99.9 | |
| CO - EPAP CONTRIBUTION | 9.55 | 0.65 | 0.03 | -0- | 2.65 | 0.90 | 0.57 | 0.43 | 0.18 | |
| THC - EPAP CONTRIBUTION | 0.22 | 0.02 | 0.02 | 0.01 | 0.15 | 0.01 | 0.01 | 0.01 | -0- | |
| NO _x - EPAP CONTRIBUTION | 0.43 | 0.29* | 1.10 | 0.48 | 0.53 | 0.47 | 0.52 | 0.61 | 0.65 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* --- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX B-6-a.

P & W VORRIX COMBUSTOR DATA, CONFIGURATION S-18

IDLE, APPROACH, CLIMBOUT AND TAKEOFF DATA

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | APPROACH | | | | CLIMBOUT | TAKE-OFF | | | | |
|-------------------------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | CL-1 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 |
| FUELING MODE | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.93 | 6.88 | 6.84 | 6.80 | 6.94 | 6.82 | 6.81 | 6.80 | 6.84 | 6.90 | 6.76 |
| FUEL-AIR RATIO-PILOT | .0126 | .0027 | .0055 | .0081 | .0107 | .0030 | .0032 | .0042 | .0053 | .0073 | .0097 |
| FUEL-AIR RATIO-TOTAL | .0126 | .0134 | .0137 | .0133 | .0134 | .0201 | .0218 | .0216 | .0215 | .0217 | .0217 |
| CO - E.I. | 70.0 | 67.0 | 25.8 | 19.3 | 18.8 | 24.7 | 34.9 | 27.5 | 22.7 | 12.5 | 8.2 |
| THC - E.I. | 1.2 | 41.3 | 1.9 | 0.4 | 1.4 | 0.9 | 0.8 | 0.4 | 0.3 | 0.1 | 0.1 |
| NO _x - E.I. | 3.2 | 3.7 | 7.5 | 7.3 | 6.4 | 10.5 | 12.7 | 14.5 | 16.1 | 16.1 | 14.9 |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 98.2 | 94.3 | 99.2 | 99.5 | 99.4 | 99.3 | 99.1 | 99.3 | 99.4 | 99.7 | 99.8 |
| PATTERN FACTOR | ---- | ---- | 0.79 | ---- | ---- | ---- | ---- | ---- | 0.78 | ---- | ---- |
| CO - EPAP CONTRIBUTION | 12.04 | 4.57 | 1.76 | 1.32 | 1.28 | 2.63 | 1.44 | 1.14 | 0.94 | 0.52 | 0.34 |
| THC - EPAP CONTRIBUTION | 0.21 | 2.82 | 0.13 | 0.03 | 0.10 | 0.10 | 0.03 | 0.02 | 0.01 | -0- | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | |
|---|-------|------|------|------|------|------|------|------|------|------|------|
| CO - E.I. | 69.9 | 63.3 | 23.1 | 16.8 | 16.5 | 14.5 | 21.8 | 15.7 | 12.0 | 4.8 | 2.2 |
| THC - E.I. | 1.2 | 33.4 | 1.5 | 0.3 | 1.1 | 0.3 | 0.3 | 0.1 | 0.1 | -0- | -0- |
| NO _x - E.I. | 2.8 | 3.6 | 7.1 | 7.1 | 6.1 | 14.5 | 20.2 | 22.9 | 25.5 | 24.8 | 23.9 |
| COMBUSTION EFFICIENCY % | 98.2 | 95.2 | 99.3 | 99.6 | 99.5 | 99.6 | 99.5 | 99.6 | 99.7 | 99.9 | 100 |
| CO - EPAP CONTRIBUTION | 12.02 | 4.32 | 1.58 | 1.15 | 1.13 | 1.54 | 0.90 | 0.65 | 0.50 | 0.20 | 0.09 |
| THC - EPAP CONTRIBUTION | 0.21 | 2.28 | 0.10 | 0.02 | 0.08 | 0.04 | 0.01 | 0.01 | -0- | -0- | -0- |
| NO _x - EPAP CONTRIBUTION. | 0.48 | 0.25 | 0.48 | 0.48 | 0.41 | 1.54 | 0.84 | 0.95 | 1.06 | 1.03 | 0.99 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX B-6-b

VORBITX CONFIGURATION S-18 CONTINUED

1. TEST RIG DATA

| ENGINE CONDITION | CRUISE | | |
|-------------------------------|--------------------|--------------------|--------------------|
| READING NUMBER | CR-1 | CR-2 | CR-3 |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 6.81 | 6.81 | 6.81 |
| FUEL-AIR RATIO-PILOT | .0050 | .0059 | .0069 |
| FUEL-AIR RATIO-TOTAL | .0201 | .0201 | .0200 |
| CO - E.I. | 21.5 | 17.3 | 15.1 |
| THC - E.I. | 0.3 | 0.2 | 0.1 |
| NO _x - E.I. | 12.3 | 12.3 | 12.8 |
| SMOKE NO. | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.5 | 99.6 | 99.6 |
| PATTERN FACTOR | ---- | ---- | ---- |
| CO - EPAP CONTRIBUTION | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | ---- | ---- | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | |
|---|------|------|------|
| CO - E.I. | 17.9 | 14.0 | 11.9 |
| THC - E.I. | 0.2 | 0.2 | 0.1 |
| NO _x - E.I. | 13.0 | 12.8 | 13.5 |
| COMBUSTION EFFICIENCY % | 99.6 | 99.7 | 99.7 |
| CO - EPAP CONTRIBUTION | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | ---- | ---- | ---- |
| NO _x - EPAP CONTRIBUTION. | ---- | ---- | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

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APPENDIX B-7

P & W VORBIK COMBUSTOR DATA, CONFIGURATION S-19

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLEED | TAKE-OFF | | |
|-------------------------------|---------------|--------------------|--|--|
| READING NUMBER | I-1 | TO-1 | | |
| FUELING MODE | PILOT ONLY | PILOT & MAIN | | |
| INLET PRESSURE ATM. | 2.97 | 6.86 | | |
| FUEL-AIR RATIO-PILOT | .0126 | .0078 | | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0228 | | |
| CO - E.I. | 63.0 | 10.6 | | |
| THC - E.I. | 0.3 | 0.2 | | |
| NO _x - E.I. | 3.2 | ---- | | |
| SMOKE NO. | ---- | ---- | | |
| COMBUSTION EFFICIENCY % | 98.5 | 99.7 | | |
| EATERN FACTOR | ---- | ---- | | |
| CO - EPAP CONTRIBUTION | 10.84 | 0.44 | | |
| THC - EPAP CONTRIBUTION | 0.04 | 0.01 | | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | |
|---|-------|-------|--|--|
| CO - E.I. | 63.6 | 3.6 | | |
| THC - E.I. | 0.3 | 0.1 | | |
| NO _x - E.I. | 2.7 | | | |
| COMBUSTION EFFICIENCY % | 98.5 | 99.9 | | |
| CO - EPAP CONTRIBUTION | 10.94 | 0.15 | | |
| THC - EPAP CONTRIBUTION | 0.04 | 0.003 | | |
| NO _x - EPAP CONTRIBUTION. | 0.46 | ---- | | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX B-8 -a

P & W VORBITZ COMBUSTOR DATA, CONFIGURATION S-20

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | IDLE UNBLED | APPROACH | | | | | CLIMBOUT | | TAKE-OFF | | | |
|-------------------------------|---------------|----------------|--------------------|--------------------|----------------------------|----------------------------|----------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | I-2 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | CL-1 | CL-2 | TO-1 | TO-2 | TO-3 | TO-4 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & 7/11 MAIN | PILOT & 7/11 MAIN | PILOT & 7/11 MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.94 | 3.76 | 6.75 | 6.83 | 6.82 | 6.82 | 6.80 | 6.78 | 6.77 | 6.83 | 6.85 | 6.83 | 6.79 |
| FUEL-AIR RATIO-PILOT | .0126 | .0103 | .0070 | .0104 | .0062 | .0069 | .0105 | .0041 | .0076 | .0022 | .0033 | .0044 | .0044 |
| FUEL-AIR RATIO-TOTAL | .0126 | .0103 | .0142 | .0140 | .0130 | .0139 | .0140 | .0194 | .0205 | .0209 | .0213 | .0215 | .0215 |
| CO - E.I. | 46.2 | 28.4 | 16.5 | 11.8 | 25.3 | 19.5 | 9.9 | 22.4 | 7.4 | 63.7 | 43.0 | 29.0 | 21.0 |
| THC - E.I. | 6.4 | 3.7 | 0.8 | 0.2 | 4.8 | 2.7 | 0.4 | 0.7 | -0- | 12.4 | 1.9 | 0.4 | 0.2 |
| NO _x - E.I. | 3.5 | 4.3 | 5.9 | 9.4 | 5.2 | 5.9 | 9.6 | 8.1 | 10.7 | 8.3 | 8.8 | 9.6 | 10.6 |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 4. | 2. | 4. | ---- |
| COMBUSTION EFFICIENCY % | 98.3 | 99.0 | 99.5 | 99.7 | 98.9 | 99.3 | 99.7 | 99.4 | 99.8 | 97.3 | 98.8 | 99.3 | 99.5 |
| PATTERN FACTOR | 0.40 | ---- | 0.49 | ---- | ---- | 0.33 | ---- | 0.63 | ---- | ---- | ---- | 0.66 | ---- |
| CO - EPAP CONTRIBUTION | 7.95 | 5.01 | 1.13 | 0.80 | 1.73 | 1.33 | 0.68 | 2.39 | 0.79 | 2.64 | 1.78 | 1.20 | 0.87 |
| THC - EPAP CONTRIBUTION | 1.10 | 0.65 | 0.05 | 0.01 | 0.32 | 0.18 | 0.03 | 0.07 | -0- | 0.51 | 0.08 | 0.01 | 0.01 |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | |
|--|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| CO - E.I. | 46.3 | 26.4 | 11.0 | 9.7 | 22.6 | 17.0 | 7.9 | 12.6 | 2.1 | 46.8 | 28.7 | 17.0 | 10.7 |
| THC - E.I. | 6.4 | 3.5 | 0.6 | 0.2 | 3.8 | 2.2 | 0.3 | 0.3 | -0- | 4.0 | 0.6 | 0.1 | 0.1 |
| NO _x - E.I. | 3.0 | 3.9 | 5.4 | 8.6 | 5.0 | 5.6 | 9.0 | 11.5 | 15.0 | 13.0 | 13.7 | 14.6 | 13.7 |
| COMBUSTION EFFICIENCY % | 98.3 | 99.0 | 99.6 | 99.8 | 99.1 | 99.4 | 99.8 | 99.7 | 100 | 98.5 | 99.3 | 99.6 | 99.7 |
| CO - EPAP CONTRIBUTION | 7.97 | 4.66 | 0.96 | 0.66 | 1.54 | 1.16 | 0.54 | 1.35 | 0.23 | 1.94 | 1.19 | 0.70 | 0.44 |
| THC - EPAP CONTRIBUTION | 1.10 | 0.62 | 0.01 | 0.01 | 0.26 | 0.15 | 0.02 | 0.03 | -0- | 0.17 | 0.03 | 0.005 | 0.003 |
| NO _x - EPAP CONTRIBUTION | 0.51 | 0.69 | 0.37 | 0.59 | 0.34 | 0.38 | 0.61 | 1.22 | 1.59 | 0.54 | 0.57 | 0.61 | 0.57 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX B-8-b

VORBIX CONFIGURATION S-20 CONTINUED

1. TEST RIG DATA

| ENGINE CONDITION | TAKEOFF | CRUISE | | | | | |
|-------------------------------|----------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--|
| READING NUMBER | TO-6 | CR-1 | CR-2 | CR-3 | CR-4 | CR-5 | |
| FUELING MODE | PILOT & 7/11 MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 6.95 | 6.81 | 6.80 | 6.82 | 6.90 | 6.78 | |
| FUEL-AIR RATIO-PILOT | .0077 | .0040 | .0045 | .0061 | .0077 | .0082 | |
| FUEL-AIR RATIO-TOTAL | .0229 | .0205 | .0205 | .0206 | .0224 | .0206 | |
| CO - E.I. | 10.3 | 30.8 | 33.2 | 15.9 | 20.3 | 7.8 | |
| THC - E.I. | 0.1 | 0.1 | 0.9 | 0.2 | 0.9 | -0- | |
| NO _x - E.I. | 12.7 | 7.0 | 7.2 | 8.1 | 9.3 | 10.0 | |
| SMOKE NO. | 3. | ---- | ---- | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.7 | 99.2 | 99.2 | 99.6 | 99.5 | 99.8 | |
| PATTERN FACTOR | ---- | ---- | 0.63 | ---- | ---- | ---- | |
| CO - EPAP CONTRIBUTION | 0.43 | ---- | ---- | ---- | ---- | ---- | |
| THC - EPAP CONTRIBUTION | 0.004 | ---- | ---- | ---- | ---- | ---- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | |
|---|-------|------|------|------|------|------|--|
| CO - E.I. | 3.4 | 26.7 | 29.0 | 12.7 | 16.9 | 5.3 | |
| THC - E.I. | -0- | 0.1 | 0.7 | 0.2 | 0.7 | -0- | |
| NO _x - E.I. | 18.5 | 7.1 | 7.1 | 8.2 | 9.1 | 10.0 | |
| COMBUSTION EFFICIENCY % | 99.9 | 99.4 | 99.3 | 99.7 | 99.5 | 99.9 | |
| CO - EPAP CONTRIBUTION | 0.14 | ---- | ---- | ---- | ---- | ---- | |
| THC - EPAP CONTRIBUTION | 0.001 | ---- | ---- | ---- | ---- | ---- | |
| NO _x - EPAP CONTRIBUTION. | 0.76 | ---- | ---- | ---- | ---- | ---- | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

P & W VORRIX COMBUSTOR DATA, CONFIGURATION S-21

. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | IDLE UNBLED | APPROACH | | | NO CLIMB. DATA | TAKE-OFF | | | | NO CRUISE DATA |
|-------------------------------|---------------|----------------|--------------------|--------------------|--------------------|-------------------|--------------------|--------------------|--------------------|--------------------|----------------|
| READING NUMBER | ID-1 | ID-2 | APP-1 | APP-2 | APP-3 | | TO-1 | TO-2 | TO-3 | TO-4 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.93 | 3.62 | 6.80 | 6.60 | 6.78 | | 6.72 | 6.82 | 6.78 | 6.82 | |
| FUEL-AIR RATIO-PILOT | .0126 | .0107 | .0058 | .0075 | .0102 | | .0031 | .0041 | .0069 | .0075 | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0107 | .0140 | .0130 | .0142 | | .0227 | .0225 | .0227 | .0223 | |
| CO - E.I. | 43.0 | 30.4 | 57.5 | 35.5 | 23.1 | | 99.9 | 43.1 | 14.7 | 12.3 | |
| THC - E.I. | 3.2 | 1.8 | 29.7 | 12.5 | 2.6 | | 26.5 | 1.8 | 0.8 | 0.4 | |
| NO _x - E.I. | 3.2 | 3.6 | 4.5 | 5.4 | 7.3 | | 7.4 | 9.3 | 13.3 | 14.1 | |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | | ---- | ---- | ---- | 1. | |
| COMBUSTION EFFICIENCY % | 98.7 | 99.1 | 95.7 | 97.9 | 99.2 | | 95.0 | 98.8 | 99.6 | 99.7 | |
| PATTERN FACTOR | 0.39 | ---- | ---- | 0.45 | ---- | | ---- | ---- | ---- | ---- | |
| CO - EPAP CONTRIBUTION | 7.40 | 5.36 | 3.92 | 2.42 | 1.58 | | 4.14 | 1.78 | 0.61 | 0.51 | |
| THC - EPAP CONTRIBUTION | 0.55 | 0.32 | 2.03 | 0.85 | 0.18 | | 1.10 | 0.07 | 0.03 | 0.02 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | |
|---|------|------|------|------|------|--|------|------|------|------|--|
| CO - E.I. | 43.0 | 27.0 | 53.8 | 32.0 | 20.4 | | 79.5 | 28.7 | 6.2 | 4.6 | |
| THC - E.I. | 3.2 | 1.7 | 23.7 | 9.7 | 2.1 | | 8.4 | 0.6 | 0.2 | 0.1 | |
| NO _x - E.I. | 2.8 | 3.2 | 4.3 | 5.5 | 6.6 | | 11.6 | 14.0 | 20.0 | 21.4 | |
| COMBUSTION EFFICIENCY % | 98.7 | 99.2 | 96.4 | 98.3 | 99.3 | | 97.3 | 99.3 | 99.8 | 99.9 | |
| CO - EPAP CONTRIBUTION | 7.40 | 4.76 | 3.67 | 2.18 | 1.39 | | 3.29 | 1.19 | 0.26 | 0.19 | |
| THC - EPAP CONTRIBUTION | 0.55 | 0.29 | 1.62 | 0.66 | 0.14 | | 0.35 | 0.02 | 0.01 | 0.01 | |
| NO _x - EPAP CONTRIBUTION. | 0.48 | 0.57 | 0.29 | 0.37 | 0.45 | | 0.48 | 0.58 | 0.83 | 0.89 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX C

This appendix contains summaries of test rig data for all of the Pratt & Whitney hybrid combustor configurations evaluated in Phase II of the Experimental Clean Combustor Program. Data are presented in two groupings:

1. Test Rig Data - In this section, data are presented as they were obtained in the test rig with one exception. In setting test point conditions, it was rarely possible to operate precisely at the design point fuel-air ratio. Thus, when more than fuel-air ratio was investigated at a test condition, the general procedure used was to plot the emissions against fuel-air ratio and determine emission levels at the design point fuel-air ratio by interpolation. When only one fuel-air ratio was investigated at a test condition, emission levels at that value are reported.

2. Data Corrected to Engine Pressures - Correlations which were used to extrapolate test rig data to engine conditions are contained in the Data Correlation Procedures section of the report. Calculations of EPAP values were made according to the procedures described in the EPAP Calculations section of the report.

APPENDIX C-1.

P & W HYBRID COMBUSTOR DATA, CONFIGURATION H-1

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLEED | TAKE-OFF | | | | DATA NOT OBTAINED AT APPROACH, CLIMB, CRUISE |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--|
| READING NUMBER | I-1 | TO.-1 | TO.-2 | TO.-3 | TO.-4 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.96 | 6.80 | 6.80 | 6.81 | 6.74 | |
| FUEL-AIR RATIO-PILOT | .0126 | .0155 | .0046 | .0056 | .0068 | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0155 | .0214 | .0215 | .0215 | |
| CO - E.I. | 13.0 | 2.3 | 49.0 | 31.5 | 6.6 | |
| THC - E.I. | 8.6 | 1.5 | 29.2 | 18.5 | 6.3 | |
| NO _x - E.I. | 3.3 | 20.2 | 8.7 | 9.4 | 10.2 | |
| SMOKE NO. | --- | --- | --- | 2 | --- | |
| COMBUSTION EFFICIENCY % | 98.8 | 99.8 | 95.9 | 97.4 | 99.2 | |
| PATTERN FACTOR | 1.33 | --- | --- | --- | --- | |
| CO - EPAP CONTRIBUTION | 2.24 | 0.10 | 2.03 | 1.30 | 0.27 | |
| THC - EPAP CONTRIBUTION | 1.48 | 0.06 | 1.21 | 0.77 | 0.26 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | |
|--|------|------|------|------|------|--|
| CO - E.I. | 13.2 | 0.5 | 33.7 | 19.0 | 1.4 | |
| THC - E.I. | 8.7 | 0.2 | 9.4 | 6.0 | 2.0 | |
| NO _x - E.I. | 2.9 | 36.0 | 13.6 | 14.7 | 16.0 | |
| COMBUSTION EFFICIENCY % | 98.8 | 100 | 98.3 | 99.0 | 99.8 | |
| CO - EPAP CONTRIBUTION | 2.27 | 0.01 | 1.40 | 0.79 | 0.06 | |
| THC - EPAP CONTRIBUTION | 1.50 | 0.02 | 0.39 | 0.25 | 0.08 | |
| NO _x - EPAP CONTRIBUTION | 0.50 | 1.49 | 0.56 | 0.61 | 0.66 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

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APPENDIX C-2

P & W HYBRID COMBUSTOR DATA, CONFIGURATION H-2

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | APPROACH | | CLIMBOUT | TAKE-OFF | | | NO CRUISE DATA |
|-------------------------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | CL-1 | TO-1 | TO-2 | TO-3 | |
| FUELING MODE | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.95 | 6.76 | 6.73 | 6.80 | 6.96 | 6.86 | 6.89 | |
| FUEL-AIR RATIO-PILOT | .0126 | .0068 | .0104 | .0072 | .0044 | .0055 | .0079 | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0135 | .0132 | .0204 | .0217 | .0224 | .0228 | |
| CO - E.I. | 11.5 | 111.6 | 13.6 | 28.5 | 58.7 | 12.1 | 10.3 | |
| THC - E.I. | 0.9 | 300+ | 289.4 | 3.5 | 18.5 | 0.6 | 0.5 | |
| NO _x - E.I. | 4.0 | 1.8 | 3.6 | 7.0 | 11.7 | 11.7 | 9.7 | |
| SMOKE NO. | ---- | ----- | ----- | ---- | ---- | 1. | ---- | |
| COMBUSTION EFFICIENCY % | 99.7 | 67.0 | 70.0 | 99.0 | 96.2 | 99.7 | 99.7 | |
| PATTERN FACTOR | 1.49 | ----- | ----- | ---- | ---- | ----- | 0.44 | |
| CO - EPAP CONTRIBUTION | 1.98 | 7.61 | 2.97 | 3.04 | 2.43 | 0.50 | 0.43 | |
| THC - EPAP CONTRIBUTION | 0.15 | 20.46 | 19.74 | 0.37 | 0.77 | 0.02 | 0.02 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | |
|---|------|-------|-------|------|------|------|------|--|
| CO - E.I. | 11.7 | 107. | 10.1 | 17.6 | 12.5 | 1.5 | 3.4 | |
| THC - E.I. | 0.9 | 239. | 229. | 1.3 | 6.1 | 0.2 | 0.2 | |
| NO _x - E.I. | 3.5 | 2.1 | 4.2 | 10.3 | 18.3 | 17.3 | 14.6 | |
| COMBUSTION EFFICIENCY % | 99.6 | 73.6 | 76.2 | 99.5 | 98.4 | 99.9 | 99.9 | |
| CO - EPAP CONTRIBUTION | 2.01 | 7.30 | 2.73 | 1.87 | 1.76 | 0.19 | 0.14 | |
| THC - EPAP CONTRIBUTION | 0.15 | 16.30 | 15.62 | 0.14 | 0.25 | 0.01 | 0.01 | |
| NO _x - EPAP CONTRIBUTION. | 0.61 | 0.14 | 0.28 | 1.10 | 0.76 | 0.72 | 0.60 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX C-3

P & W HYBRID COMBUSTOR DATA, CONFIGURATION H-3

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | IDLE UNBLED | APPROACH | | | TAKE-OFF | NO DATA OBTAINED AT CLIMBOUT & CRUISE |
|-------------------------------|---------------|----------------|---------------|--------------|-------------------------------|--------------|---------------------------------------|
| READING NUMBER | I-1 | I-2 | APP-1 | APP-2 | APP-3 | TO-1 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | MAIN ONLY | MAIN ONLY, 7/11 inj. | MAIN ONLY | |
| INLET PRESSURE ATM. | 2.94 | 3.83 | 6.70 | 6.76 | 6.76 | 6.76 | |
| FUEL-AIR RATIO-PILOT | .0126 | .0099 | .0130 | -0- | -0- | -0- | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0099 | .0130 | .0130 | .0130 | .0119 | |
| CO - E.I. | 8.0 | 24.3 | 1.9 | 15.5 | 13.4 | 0.9 | |
| THC - E.I. | 0.4 | 6.5 | 1.1 | 3.0 | 1.3 | 0.5 | |
| NO _x - E.I. | 3.8 | 2.8 | 8.7 | 7.4 | 7.1 | 11.6 | |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.8 | 98.8 | 99.9 | 99.3 | 99.6 | 100 | |
| EATTERN FACTOR | 1.02 | ---- | ---- | 0.89 | ---- | ---- | |
| CO - EPAP CONTRIBUTION | 1.38 | 4.28 | 0.13 | 1.06 | 0.91 | 0.04 | |
| THC - EPAP CONTRIBUTION | 0.06 | 1.15 | 0.08 | 0.20 | 0.09 | 0.02 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | |
|--|------|------|-------|------|------|------|--|
| CO - E.I. | 8.1 | 22.5 | 0.2 | 13.1 | 11.4 | -0- | |
| THC - E.I. | 0.4 | 6.2 | 0.9 | 2.4 | 1.1 | 0.4 | |
| NO _x - E.I. | 3.3 | 2.7 | 8.2* | 7.6 | 6.8 | 14.9 | |
| COMBUSTION EFFICIENCY % | 99.8 | 98.9 | 99.9 | 99.5 | 99.6 | 100 | |
| CO - EPAP CONTRIBUTION | 1.39 | 3.97 | 0.01 | 0.89 | 0.78 | -0- | |
| THC - EPAP CONTRIBUTION | 0.06 | 1.09 | 0.06 | 0.16 | 0.07 | 0.02 | |
| NO _x - EPAP CONTRIBUTION | 0.56 | 0.47 | 0.56* | 0.51 | 0.46 | 0.61 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSUREORIGINAL PAGE IS
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APPENDIX C-4

P & W HYBRID COMBUSTOR DATA, CONFIGURATION H-4

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | APPROACH | | CLIMBOUT | | | TAKE-OFF | | | | | | | |
|-------------------------------|---------------|---------------|---------------------------|--------------------|--------------------|--------------------|---------------|---------------|--------------|--------------|--------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | CL-1 | CL-2 | CL-3 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | TO-6 | TO-7 | TO-8 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | NO PILOT, 4/11 MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT ONLY | PILOT ONLY | MAIN ONLY | MAIN ONLY | MAIN ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.92 | 6.94 | 6.76 | 6.84 | 6.89 | 6.79 | 6.87 | 6.95 | 6.79 | 6.84 | 6.74 | 6.82 | 6.87 | 6.87 |
| FUEL-AIR RATIO-PILOT | .0126 | .0130 | -0- | .0051 | .0061 | .0075 | .0065 | .0088 | -0- | -0- | -0- | .0054 | .0073 | .0073 |
| FUEL-AIR RATIO-TOTAL | .0126 | .0130 | .0130 | .0201 | .0200 | .0201 | .0065 | .0088 | .0128 | .0151 | .0184 | .0216 | .0219 | .0219 |
| CO - E.I. | 9.0 | 1.8 | 47.0 | 80.0 | 90.1 | 101. | 29.9 | 1.8 | 2.7 | 4.0 | 12.2 | 26.7 | 4.2 | 4.2 |
| THC - E.I. | 0.6 | 0.4 | 1.6 | 79.4 | 94.1 | 111. | 5.2 | 1.8 | 0.7 | 0.6 | 0.8 | 2.6 | -0- | -0- |
| NO _x - E.I. | 3.5 | 9.1 | 6.6 | 13.9 | 12.1 | 10.3 | 4.7 | 9.4 | 17.1 | 19.9 | 19.2 | 15.4 | 15.5 | 15.5 |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.7 | 99.9 | 98.7 | 90.2 | 88.5 | 86.3 | 98.8 | 99.8 | 99.9 | 99.9 | 99.6 | 99.1 | 99.9 | 99.9 |
| PATTERN FACTOR | 1.10 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 0.47 | ---- | ---- |
| CO - EPAP CONTRIBUTION | 1.55 | 0.12 | 3.21 | 8.52 | 9.60 | 11.5 | 1.24 | 0.07 | 0.11 | 0.17 | 0.51 | 1.11 | 0.17 | 0.17 |
| THC - EPAP CONTRIBUTION | 0.10 | 0.03 | 0.11 | 8.46 | 10.0 | 11.9 | 0.22 | 0.07 | 0.03 | 0.02 | 0.03 | 0.11 | -0- | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|--|------|-------|------|------|------|------|------|------|------|------|------|------|------|------|
| CO - E.I. | 8.9 | 0.2 | 43.5 | 63.4 | 72.9 | 89.7 | ---- | ---- | ---- | 0.5 | 4.5 | 15.1 | 0.5 | 0.5 |
| THC - E.I. | 0.6 | 0.3 | 1.2 | 29.3 | 35.1 | 40.9 | ---- | ---- | ---- | 0.2 | 0.3 | 0.8 | -0- | -0- |
| NO _x - E.I. | 3.1 | 8.2* | 6.6 | 21.5 | 20.3 | 17.8 | ---- | ---- | ---- | 33.4 | 33.1 | 24.6 | 24.1 | 24.1 |
| COMBUSTION EFFICIENCY % | 99.7 | 100 | 98.9 | 95.6 | 94.8 | 93.8 | ---- | ---- | ---- | 100 | 99.9 | 99.6 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 1.53 | 0.02 | 2.97 | 6.75 | 7.76 | 9.55 | ---- | ---- | ---- | 0.02 | 0.19 | 0.63 | 0.02 | 0.02 |
| THC - EPAP CONTRIBUTION | 0.10 | 0.02 | 0.08 | 3.12 | 3.73 | 4.35 | ---- | ---- | ---- | 0.01 | 0.01 | 0.03 | -0- | -0- |
| NO _x - EPAP CONTRIBUTION | 0.53 | 0.56* | 0.45 | 2.29 | 2.16 | 1.90 | ---- | ---- | ---- | 1.38 | 1.37 | 1.02 | 1.00 | 1.00 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* - P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

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APPENDIX C-5

P & W HYBRID COMBUSTOR DATA, CONFIGURATION H-5

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLEED | APPROACH | | | | CLIMBOUT | TAKE-OFF | | | | NO CRUISE DATA |
|-------------------------------|---------------|---------------|--------------|----------------------|----------------------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | CL-1 | TO-1 | TO-2 | TO-3 | TO-4 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | MAIN ONLY | 7/11 MAIN ONLY | 4/11 MAIN ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.95 | 6.84 | 6.80 | 6.87 | 6.74 | 6.81 | 6.93 | 6.76 | 6.79 | 6.78 | |
| FUEL-AIR RATIO-PILOT | .0126 | .0130 | -0- | -0- | -0- | .0052 | .0033 | .0052 | .0074 | .0097 | |
| FUEL-AIR RATIO-TOTAL | .0126 | .0130 | .0130 | .0134 | .0128 | .0198 | .0222 | .0217 | .0217 | .0217 | |
| CO - E.I. | 16.0 | 1.4 | 142. | 81.0 | 74.8 | 33.3 | 70.1 | 13.1 | 13.0 | 16.8 | |
| THC - E.I. | 0.7 | 1.6 | 110. | 78.0 | 49.0 | 4.0 | 49.8 | 1.0 | 1.5 | 1.9 | |
| NO _x - E.I. | 4.4 | 12.2 | 3.2 | 5.3 | 6.4 | 6.6 | 10.1 | 10.6 | 10.5 | 15.5 | |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.6 | 99.8 | 85.7 | 90.3 | 93.4 | 98.8 | 93.4 | 99.6 | 99.6 | 99.4 | |
| PATTERN FACTOR | 1.84 | 1.33 | ---- | ---- | ---- | 0.26 | ---- | ---- | ---- | ---- | |
| CO - EPAP CONTRIBUTION | 2.75 | 0.10 | 9.68 | 5.57 | 5.10 | 3.55 | 2.90 | 0.54 | 0.54 | 0.70 | |
| THC - EPAP CONTRIBUTION | 0.12 | 0.11 | 7.50 | 5.32 | 3.34 | 0.43 | 2.06 | 0.04 | 0.06 | 0.08 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | |
|---|------|-------|------|------|------|------|------|------|------|------|--|
| CO - E.I. | 16.2 | 0.1 | 137. | 77.7 | 21.6 | 21.6 | 52.7 | 5.1 | 5.1 | 7.6 | |
| THC - E.I. | 0.7 | 1.3 | 87.9 | 63.0 | 38.9 | 1.5 | 16.4 | 0.3 | 0.5 | 0.6 | |
| NO _x - E.I. | 4.0 | 12.0* | 3.5 | 5.5 | 6.7 | 9.9 | 16.3 | 17.4 | 17.2 | 25.5 | |
| COMBUSTION EFFICIENCY % | 99.6 | 99.9 | 88.0 | 91.9 | 94.5 | 99.4 | 97.1 | 99.9 | 99.8 | 99.8 | |
| CO - EPAP CONTRIBUTION | 2.79 | 0.01 | 9.35 | 5.30 | 4.82 | 2.30 | 2.18 | 0.21 | 0.21 | 0.32 | |
| THC - EPAP CONTRIBUTION | 0.12 | 0.09 | 6.00 | 4.30 | 2.65 | 0.16 | 0.68 | 0.01 | 0.02 | 0.03 | |
| NO _x - EPAP CONTRIBUTION. | 0.68 | 0.77* | 0.24 | 0.38 | 0.46 | 1.05 | 0.67 | 0.72 | 0.71 | 1.05 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO EXTRAPOLATION TO ENGINE PRESSURE
x

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APPENDIX C-6

P & W HYBRID COMBUSTOR DATA, CONFIGURATION H-6

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLED | IDLE UNBLED | APPROACH | | | CLIMBOUT | TAKE-OFF | | | | | CRUISE |
|-------------------------------|---------------|----------------|---------------|--------------------|----------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | I-2 | APP-1 | APP-2 | APP-3 | CL-1 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & MAIN | 4/11 MAIN ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.93 | 3.76 | 6.76 | 6.73 | 6.88 | 6.80 | 6.89 | 6.84 | 6.85 | 6.92 | 6.95 | 6.84 |
| FUEL-AIR RATIO-PILOT | .0126 | .0103 | .0130 | .0048 | -0- | .0076 | .0022 | .0031 | .0044 | .0076 | .0093 | .0077 |
| FUEL-AIR RATIO-TOTAL | .0126 | .0103 | .0130 | .0136 | .0130 | .0194 | .0226 | .0223 | .0228 | .0215 | .0225 | .0205 |
| CO - E.I. | 9.6 | 3.9 | -0- | 81.6 | 45.0 | 33.3 | 42.9 | 62.5 | 47.8 | 18.5 | 19.8 | 39.0 |
| THC - E.I. | 4.2 | 2.9 | 0.3 | 697. | 2.0 | 4.1 | 26.4 | 41.5 | 11.3 | 3.5 | 2.1 | 8.2 |
| NO _x - E.I. | 4.2 | 3.1 | 16.0 | 1.0 | 7.4 | 8.2 | 14.6 | 13.3 | 12.8 | 11.1 | 13.2 | 7.6 |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 4. | 2. | ---- | 3. | ---- |
| COMBUSTION EFFICIENCY % | 99.4 | 99.6 | 100 | 28.4 | 98.8 | 98.8 | 96.2 | 94.4 | 97.8 | 99.2 | 99.3 | 98.3 |
| PATTERN FACTOR | 1.94 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 0.40 | ---- | ---- |
| CO - EPAP CONTRIBUTION | 1.65 | 0.69 | -0- | 5.57 | 3.07 | 3.55 | 2.07 | 2.59 | 1.98 | 0.77 | 0.82 | ---- |
| THC - EPAP CONTRIBUTION | 0.72 | 0.51 | 0.02 | 47.5 | 0.14 | 0.43 | 1.09 | 1.72 | 0.47 | 0.14 | 0.09 | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | |
|---|------|------|-------|------|------|------|------|------|------|------|------|------|
| CO - E.I. | 9.6 | 3.5 | -0- | 77.3 | 41.8 | 21.6 | 34.7 | 45.7 | 32.8 | 9.0 | 9.9 | 34.6 |
| THC - E.I. | 4.2 | 2.8 | 0.2 | 551. | 1.6 | 1.5 | 8.6 | 13.5 | 3.7 | 1.1 | 0.7 | 6.0 |
| NO _x - E.I. | 3.6 | 2.8 | 15.2* | 1.4 | 6.7 | 11.6 | 21.6 | 19.7 | 18.7 | 16.4 | 18.3 | 7.5 |
| COMBUSTION EFFICIENCY % | 99.4 | 99.6 | 100 | 43.1 | 99.0 | 99.4 | 98.3 | 97.6 | 98.9 | 99.7 | 99.7 | 98.6 |
| CO - EPAP CONTRIBUTION | 1.65 | 0.62 | -0- | 5.27 | 2.85 | 2.30 | 1.44 | 1.89 | 1.36 | 0.37 | 0.41 | ---- |
| THC - EPAP CONTRIBUTION | 0.72 | 0.49 | 0.01 | 37.6 | 0.11 | 0.16 | 0.36 | 0.56 | 0.15 | 0.05 | 0.03 | ---- |
| NO _x - EPAP CONTRIBUTION. | 0.61 | 0.50 | 0.97* | 0.10 | 0.45 | 1.23 | 0.90 | 0.81 | 0.78 | 0.68 | 0.76 | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX C-7

P & W HYBRID COMBUSTOR DATA, CONFIGURATION H-7

1. TEST RIG DATA

| ENGINE CONDITION | IDLE BLND | APPROACH | CLIMBOUT | TAKEOFF | CRUISE |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | CL-1 | TO-1 | CR-1 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.93 | 6.77 | 6.82 | 6.86 | 6.71 |
| FUEL-AIR RATIO-PILOT | .0126 | .0134 | .0076 | .0076 | .0076 |
| FUEL-AIR RATIO-TOTAL | .0126 | .0134 | .0204 | .0224 | .0206 |
| CO - E.I. | 44.0 | 30.0 | 30.5 | 14.2 | 39.6 |
| THC - E.I. | 4.5 | 0.9 | 4.2 | 1.1 | 5.7 |
| NO _x - E.I. | 3.7 | 10.7 | 10.1 | 11.0 | 8.8 |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 98.5 | 99.2 | 98.9 | 99.6 | 98.5 |
| PATTERN FACTOR | 1.43 | ---- | ---- | ---- | ---- |
| CO - EPAP CONTRIBUTION | 7.58 | 2.05 | 3.25 | 0.59 | ---- |
| THC - EPAP CONTRIBUTION | 0.77 | 0.06 | 0.45 | 0.05 | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | |
|---|------|-------|------|------|------|
| CO - E.I. | 43.9 | 21.8 | 18.5 | 5.9 | 34.9 |
| THC - E.I. | 4.4 | 0.7 | 1.6 | 0.4 | 4.1 |
| NO _x - E.I. | 3.1 | 9.5* | 14.1 | 16.1 | 9.2 |
| COMBUSTION EFFICIENCY % | 98.5 | 99.4 | 99.4 | 99.8 | 98.8 |
| CO - EPAP CONTRIBUTION | 7.56 | 1.49 | 1.97 | 0.24 | ---- |
| THC - EPAP CONTRIBUTION | 0.76 | 0.05 | 0.17 | 0.01 | ---- |
| NO _x - EPAP CONTRIBUTION. | 0.54 | 0.65* | 1.50 | 0.66 | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P⁻² NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX D

This appendix contains summaries of test rig data for all of the General Electric double/annular combustor configurations evaluated in Phase II of the Experimental Clean Combustor Program. Data are presented in two groupings:

1. Test Rig Data - In this section, data are presented as they were obtained in the test rig with one exception. In setting test point conditions, it was rarely possible to operate precisely at the design point fuel-air ratio. Thus, when more than fuel-air ratio was investigated at a test condition, the general procedure used was to plot the emissions against fuel-air ratio and determine emission levels at the design point fuel-air ratio by interpolation. When only one fuel-air ratio was investigated at a test condition, emission levels at that value are reported.

2. Data Corrected to Engine Pressures - Correlations which were used to extrapolate test rig data to engine conditions are contained in the Data Correlation Procedures section of the report. Calculations of EPAP values were made according to the procedures described in the EPAP Calculations section of the report.

APPENDIX D-1-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-1

1. TEST RIG DATA

| ENGINE CONDITION | IDLE STD. | IDLE 6% BLEED | IDLE 12% BLEED | APPROACH | | | | | | | | | |
|-------------------------------|---------------|------------------|-------------------|---------------|--------------------|--------------------|--------------------|--------------|---------------|--------------------|--------------------|--------------|--|
| READING NUMBER | I-1 | I-2 | I-3 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | APP-6 | APP-7 | APP-8 | APP-9 | APP-10 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | MAIN ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | MAIN ONLY | PILOT [®] & 1/2 MAIN |
| INLET PRESSURE ATM. | 2.94 | 2.93 | 2.94 | 3.44 | 3.42 | 3.38 | 3.38 | 3.40 | 6.88 | 6.83 | 6.87 | 6.89 | 6.89 |
| FUEL-AIR RATIO-PILOT | .0110 | .0135 | .0160 | .0138 | .0044 | .0062 | .0082 | -0- | .0137 | .0042 | .0081 | -0- | .0080 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0135 | .0160 | .0138 | .0145 | .0139 | .0141 | .0141 | .0137 | .0141 | .0139 | .0138 | .0138 |
| CO - E.I. | 47.0 | 56.8 | 78.2 | 35.3 | 135.6 | 127.7 | 100.1 | 83.2 | 13.7 | 123.5 | 81.2 | 73.0 | 61.3 |
| THC - E.I. | 10.8 | 6.9 | 7.3 | 0.4 | 46.9 | 63.2 | 79.2 | 13.5 | 0.8 | 34.2 | 44.0 | 12.1 | 25.2 |
| NO _x - E.I. | 3.3 | 3.6 | 3.6 | 7.8 | 2.1 | 2.2 | 3.3 | 2.5 | 10.3 | 2.9 | 4.8 | 3.2 | 5.0 |
| SMOKE NO. | 1.3 | ---- | ---- | 1.4 | ----- | ----- | ----- | 1.0 | 2.7 | ----- | ----- | ----- | ----- |
| COMBUSTION EFFICIENCY % | 97.8 | 98.0 | 97.4 | 99.1 | 92.1 | 90.7 | 89.7 | 96.7 | 99.6 | 93.7 | 93.7 | 97.1 | 96.1 |
| PATTERN FACTOR | 1.77 | 1.24 | 0.97 | 1.11 | 0.28 | 0.46 | 0.65 | 0.54 | 1.12 | 0.33 | 0.70 | 0.56 | 0.63 |
| CO - EPAP CONTRIBUTION | 6.42 | 7.76 | 10.7 | 3.22 | 12.37 | 11.65 | 9.13 | 7.59 | 1.25 | 11.25 | 7.41 | 6.66 | 5.59 |
| THC - EPAP CONTRIBUTION | 1.47 | 0.94 | 1.00 | 0.04 | 4.28 | 5.76 | 7.22 | 1.23 | 0.07 | 3.12 | 4.01 | 1.10 | 2.30 |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | |
|---|------|------|-------|-------|-------|-------|------|------|-------|-------|------|------|------|
| CO - E.I. | 47.3 | 57.0 | 78.6 | 7.7 | 111.1 | 103.5 | 78.1 | 62.8 | 4.7 | 112.5 | 71.8 | 64.0 | 52.8 |
| THC - E.I. | 10.9 | 7.0 | 7.5 | 0.1 | 13.7 | 18.3 | 22.9 | 3.9 | 0.5 | 20.0 | 25.8 | 7.1 | 14.8 |
| NO _x - E.I. | 3.3 | 3.7 | 3.7 | 10.7* | 3.9 | 4.4 | 6.5 | 4.7 | 12.1* | 3.8 | 6.4 | 4.3 | 6.8 |
| COMBUSTION EFFICIENCY % | 97.8 | 98.0 | 97.4 | 99.8 | 96.0 | 95.8 | 95.9 | 98.1 | 99.8 | 95.4 | 95.7 | 97.8 | 97.3 |
| CO - EPAP CONTRIBUTION | 6.46 | 7.78 | 10.73 | 0.70 | 10.13 | 9.44 | 7.12 | 5.73 | 0.43 | 10.26 | 6.55 | 5.84 | 4.82 |
| THC - EPAP CONTRIBUTION | 1.49 | 0.96 | 1.02 | 0.01 | 1.25 | 1.67 | 2.09 | 0.36 | 0.05 | 1.82 | 2.35 | 0.65 | 1.35 |
| NO _x - EPAP CONTRIBUTION. | 0.45 | 0.51 | 0.51 | 0.98* | 0.36 | 0.40 | 0.59 | 0.43 | 1.10* | 0.34 | 0.58 | 0.39 | 0.53 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

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APPENDIX D-1-b

GE DOUBLE ANNULAR CONFIGURATION D/A-1 cont.

1. TEST RIG DATA

| ENGINE CONDITION READING NUMBER | APPROACH | | | | CLIMBOUT | | | | TAKE-OFF | | | | NO CRUISE DATA |
|--|-------------------------------------|-------------------------------------|-------------------------------------|--------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|
| | APP-11 | APP-12 | APP-13 | APP-14 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 | TO-3 | TO-4 | |
| FUELING MODE | PILOT [Ⓢ] & 1/2 MAIN | PILOT [Ⓢ] & 1/2 MAIN | PILOT [Ⓢ] & 1/2 MAIN | MAIN ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 3.42 | 3.40 | 3.41 | 3.35 | 4.77 | 4.76 | 4.76 | 4.83 | 4.73 | 4.74 | 4.74 | 4.73 | |
| FUEL-AIR RATIO-PILOT | .0043 | .0063 | .0083 | -0- | .0032 | .0044 | .0063 | .0101 | .0033 | .0043 | .0063 | .0101 | |
| FUEL-AIR RATIO-TOTAL | .0139 | .0142 | .0141 | .0138 | .0216 | .0216 | .0214 | .0209 | .0233 | .0233 | .0233 | .0228 | |
| CO - E.I. | 96.5 | 81.0 | 76.6 | 78.2 | 11.8 | 7.3 | 6.2 | 19.4 | 6.7 | 4.2 | 3.0 | 6.9 | |
| THC - E.I. | 19.8 | 36.0 | 32.6 | 123.1 | 0.4 | 0.5 | 0.7 | 1.8 | 0.1 | 0.1 | 0.1 | 0.3 | |
| NO _x - E.I. | 2.0 | 2.6 | 3.9 | 2.1 | 6.1 | 6.0 | 6.5 | 12.9 | 5.9 | 6.4 | 7.2 | 11.2 | |
| SMOKE NO. | ----- | ----- | ----- | 0.5 | ----- | 0.8 | ----- | ----- | 0.5 | ----- | ----- | ----- | |
| COMBUSTION EFFICIENCY % | 92.8 | 94.5 | 95.0 | 85.9 | 99.7 | 99.8 | 99.8 | 99.4 | 99.8 | 99.9 | 99.9 | 99.8 | |
| PATTERN FACTOR | 0.93 | 0.68 | 0.81 | 1.92 | 0.40 | 0.35 | 0.21 | 0.30 | 0.41 | 0.33 | 0.26 | 0.25 | |
| CO - EPAP CONTRIBUTION | 8.80 | 7.39 | 6.94 | 7.13 | 1.76 | 1.09 | 0.92 | 2.89 | 0.38 | 0.24 | 0.17 | 0.39 | |
| THC - EPAP CONTRIBUTION | 4.54 | 3.28 | 2.97 | 11.23 | 0.06 | 0.07 | 0.10 | 0.27 | 0.01 | 0.01 | 0.01 | 0.02 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | |
|--|------|------|------|------|------|------|------|------|------|------|-------|-------|--|
| CO - E.I. | 75.0 | 60.9 | 56.9 | 58.1 | 2.6 | 0.9 | 0.6 | 6.7 | 0.6 | 0.1 | 0.1 | 0.6 | |
| THC - E.I. | 14.6 | 10.5 | 9.5 | 35.2 | 0.1 | 0.1 | 0.1 | 0.3 | -0- | -0- | -0- | -0- | |
| NO _x - E.I. | 3.9 | 4.9 | 7.4 | 4.4 | 14.4 | 14.4 | 15.7 | 26.4 | 15.1 | 16.3 | 18.5 | 29.4 | |
| COMBUSTION EFFICIENCY % | 96.8 | 97.5 | 97.7 | 95.1 | 99.9 | 100 | 100 | 99.8 | 100 | 100 | 100 | 100 | |
| CO - EPAP CONTRIBUTION | 6.84 | 5.55 | 5.19 | 5.39 | 0.39 | 0.13 | 0.09 | 1.00 | 0.03 | 0.01 | 0.005 | 0.004 | |
| THC - EPAP CONTRIBUTION | 1.33 | 0.96 | 0.87 | 3.21 | 0.01 | 0.01 | 0.01 | 0.04 | -0- | -0- | -0- | -0- | |
| NO _x - EPAP CONTRIBUTION | 0.36 | 0.45 | 0.67 | 0.40 | 2.15 | 2.14 | 2.33 | 3.92 | 0.86 | 0.93 | 1.05 | 1.68 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

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APPENDIX D-2-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-2

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | CLIMBOUT | | | | TAKE-OFF | | | | |
|-------------------------|------------|------------|--------------|--------------|-----------|--------------|--------------|--------------|--------------|-----------|--------------|--------------|--------------|--------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | MAIN ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | MAIN ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.94 | 3.39 | 6.77 | 6.80 | 6.79 | 4.77 | 4.78 | 4.73 | 4.72 | 4.71 | 4.72 | 4.72 | 4.74 | 4.74 |
| FUEL-AIR RATIO-PILOT | .0110 | .0131 | .0041 | .0081 | -0- | .0031 | .0042 | .0063 | .0102 | -0- | .0031 | .0041 | .0061 | .0101 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0131 | .0141 | .0138 | .0140 | .0215 | .0215 | .0217 | .0216 | .0231 | .0233 | .0231 | .0231 | .0231 |
| CO - E.I. | 44.9 | 29.1 | 109. | 62.8 | 58.7 | 13.6 | 7.6 | 14.9 | 9.9 | 7.5 | 8.5 | 6.1 | 3.8 | 5.5 |
| THC - E.I. | 9.8 | 0.7 | 21.3 | 21.2 | 10.9 | 0.5 | 0.3 | 0.3 | 0.4 | 0.5 | 0.9 | 1.2 | 3.0 | 1.7 |
| NO _x - E.I. | 3.7 | 9.0 | 3.7 | 7.9 | 1.2 | 6.3 | 6.2 | 7.6 | 15.1 | 9.7 | 7.8 | 7.4 | 8.2 | 16.3 |
| SMOKE NO. | 1. | -0- | ---- | ---- | 1. | ---- | -0- | ---- | ---- | ---- | 1. | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 98.0 | 99.3 | 95.3 | 96.4 | 97.5 | 99.6 | 99.8 | 99.9 | 99.7 | 99.8 | 99.7 | 99.7 | 99.6 | 99.7 |
| PATTERN FACTOR | 1.23 | 1.42 | 1.36 | 0.72 | ---- | 0.51 | 0.66 | 0.37 | 0.37 | 0.50 | 0.54 | 0.57 | 0.41 | 0.31 |
| CO - EPAP CONTRIBUTION | 6.13 | 2.65 | 9.96 | 5.73 | 5.35 | 2.02 | 1.13 | 0.73 | 1.47 | 0.13 | 0.49 | 0.35 | 0.22 | 0.31 |
| THC - EPAP CONTRIBUTION | 1.34 | 0.05 | 1.94 | 1.93 | 0.99 | 0.07 | 0.04 | 0.04 | 0.06 | 0.03 | 0.05 | 0.07 | 0.17 | 0.10 |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | 45.2 | 5.0 | 98.5 | 54.0 | 50.1 | 3.5 | 1.0 | 0.3 | 1.8 | 0.8 | 1.1 | 0.5 | 0.1 | 0.3 |
|-------------------------------------|------|-------|------|------|------|------|------|------|------|-------|-------|------|------|------|
| THC - E.I. | 9.9 | 0.2 | 12.3 | 12.3 | 6.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.3 |
| NO _x - E.I. | 3.4 | 11.4* | 4.6 | 10.7 | 5.3 | 13.8 | 13.5 | 16.5 | 33.5 | 22.4 | 18.4 | 17.3 | 18.9 | 37.8 |
| COMBUSTION EFFICIENCY % | 98.0 | 99.0 | 96.5 | 97.5 | 98.2 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 6.17 | 0.46 | 8.98 | 4.92 | 4.57 | 0.52 | 0.15 | 0.04 | 0.27 | 0.04 | 0.06 | 0.03 | 0.01 | 0.02 |
| THC - EPAP CONTRIBUTION | 1.35 | 0.02 | 1.12 | 1.12 | 0.58 | 0.01 | 0.01 | 0.01 | 0.01 | 0.005 | 0.008 | 0.01 | 0.03 | 0.02 |
| NO _x - EPAP CONTRIBUTION | 0.47 | 1.04* | 0.42 | 0.91 | 0.48 | 2.05 | 2.00 | 2.45 | 4.99 | 1.28 | 1.05 | 0.99 | 1.08 | 2.16 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX D-2-b

GE DOUBLE/ANNULAR CONFIGURATION D/A-2 cont.

1. TEST RIG DATA

| ENGINE CONDITION READING NUMBER | TAKE-OFF | | | NO CRUISE DATA OBTAINED |
|--|--------------------|--------------------|--------------------|-------------------------|
| | TO-6 | TO-7 | TO-8 | |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 6.80 | 6.77 | 6.80 | |
| FUEL-AIR RATIO-PILOT | .0031 | .0040 | .0060 | |
| FUEL-AIR RATIO-TOTAL | .0229 | .0228 | .0226 | |
| CO - E.I. | 6.3 | 3.4 | 1.9 | |
| THC - E.I. | 0.3 | 0.2 | 0.2 | |
| NO _x - E.I. | 9.6 | 9.1 | 10.5 | |
| SMOKE NO. | 1. | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.8 | 99.9 | 99.9 | |
| PATTERN FACTOR | 0.45 | 0.39 | 0.50 | |
| CO - EPAP CONTRIBUTION | 0.36 | 0.19 | 0.11 | |
| THC - EPAP CONTRIBUTION | 0.02 | 0.01 | 0.01 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | |
|--|-------|-------|-------|--|
| CO - E.I. | 0.8 | 0.2 | 0.1 | |
| THC - E.I. | 0.1 | 0.1 | 0.1 | |
| NO _x - E.I. | 18.7 | 18.1 | 20.9 | |
| COMBUSTION EFFICIENCY % | 100 | 100 | 100 | |
| CO - EPAP CONTRIBUTION | 0.05 | 0.01 | 0.006 | |
| THC - EPAP CONTRIBUTION | 0.004 | 0.003 | 0.003 | |
| NO _x - EPAP CONTRIBUTION | 1.07 | 1.03 | 1.19 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-3-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-3

1. TEST RIG DATA

| ENGINE CONDITION READING NUMBER | IDLE STD. | IDLE 6% BLEED | IDLE 12% BLEED | APPROACH | | CLIMBOUT | | | | TAKE-OFF | | | |
|--|---------------|------------------|-------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------|--------------------|--------------------|--------------------|
| | I-1 | I-2 | I-3 | APP-1 | APP-2 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 | TO-3 | TO-4 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | MAIN ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.96 | 2.91 | 2.87 | 3.43 | 6.79 | 4.74 | 4.73 | 4.75 | 4.74 | 4.72 | 4.73 | 4.73 | 4.72 |
| FUEL-AIR RATIO-PILOT | .0110 | .0130 | .0153 | .0140 | .0140 | .0029 | .0040 | .0061 | .0098 | -0- | .0030 | .0041 | .0060 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0130 | .0153 | .0140 | .0140 | .0211 | .0214 | .0215 | .0210 | .0231 | .0233 | .0234 | .0231 |
| CO - E.I. | 66.0 | 80.5 | 90.8 | 52.0 | 30.5 | 17.2 | 11.7 | 9.3 | 22.2 | 15.5 | 12.2 | 8.4 | 6.5 |
| THC - E.I. | 34.5 | 37.6 | 37.6 | 0.9 | 0.2 | 0.6 | 0.2 | 0.2 | 0.8 | 0.4 | 0.3 | 0.1 | 0.1 |
| NO _x - E.I. | 3.4 | 3.3 | 3.1 | 6.9 | 9.1 | 8.0 | 8.2 | 9.7 | 13.6 | 11.9 | 10.4 | 10.3 | 11.1 |
| SMOKE NO. | 2. | ---- | ---- | 2. | 16. | ---- | -0- | ---- | ---- | ---- | -0- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 95.0 | 94.4 | 94.1 | 98.7 | 99.3 | 99.5 | 99.7 | 99.8 | 99.4 | 99.6 | 99.7 | 99.8 | 99.8 |
| PATTERN FACTOR | 1.55 | 1.29 | 1.10 | 1.36 | 1.33 | 0.47 | 0.45 | 0.38 | 0.64 | 0.52 | 0.49 | 0.38 | 0.34 |
| CO - EPAP CONTRIBUTION | 9.01 | 10.99 | 12.40 | 4.74 | 2.78 | 2.56 | 1.74 | 1.38 | 3.30 | 0.89 | 0.70 | 0.48 | 0.37 |
| THC - EPAP CONTRIBUTION | 4.71 | 5.13 | 5.13 | 0.08 | 0.02 | 0.09 | 0.03 | 0.03 | 0.12 | 0.02 | 0.02 | 0.006 | 0.006 |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | |
|--|------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|
| CO - E.I. | 66.7 | 80.3 | 89.8 | 35.3 | 23.8 | 5.4 | 2.5 | 1.6 | 8.4 | 14.0 | 2.5 | 1.0 | 0.5 |
| THC - E.I. | 35.0 | 37.9 | 37.6 | 0.3 | 0.1 | 0.1 | 0.01 | 0.01 | 0.2 | 0.06 | 0.01 | 0.02 | 0.02 |
| NO _x - E.I. | 3.1 | 3.2 | 3.0 | 8.4* | 9.4* | 18.1 | 18.2 | 21.6 | 30.2 | 28.2 | 24.2 | 23.5 | 26.3 |
| COMBUSTION EFFICIENCY % | 94.9 | 94.3 | 94.1 | 99.2 | 99.4 | 99.9 | 99.9 | 100 | 99.8 | 99.9 | 99.9 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 9.11 | 10.97 | 12.26 | 3.22 | 2.17 | 0.80 | 0.38 | 0.23 | 1.25 | 0.23 | 0.14 | 0.06 | 0.03 |
| THC - EPAP CONTRIBUTION | 4.78 | 5.17 | 5.13 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | -0- | -0- | -0- | -0- |
| NO _x - EPAP CONTRIBUTION | 0.43 | 0.43 | 0.40 | 0.77* | 0.85* | 2.70 | 2.71 | 3.22 | 4.49 | 1.61 | 1.38 | 1.34 | 1.50 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x extrapolation to engine pressureORIGINAL PAGE IS
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APPENDIX D-3-b

GE DOUBLE/ANNULAR CONFIGURATION D/A-3 cont.

1. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | | | | NO CRUISE DATA OBTAINED |
|-------------------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|
| READING NUMBER | TO-5 | TO-6 | TO-7 | TO-8 | |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 4.76 | 6.80 | 6.80 | 6.80 | |
| FUEL-AIR RATIO-PILOT | .0102 | .0031 | .0042 | .0060 | |
| FUEL-AIR RATIO-TOTAL | .0234 | .0233 | .0237 | .0235 | |
| CO - E.I. | 11.1 | 9.2 | 5.6 | 4.7 | |
| THC - E.I. | 0.2 | 0.3 | 0.2 | 0.4 | |
| NO _x - E.I. | 15.7 | 12.3 | 12.6 | 13.7 | |
| SMOKE NO. | ---- | 1. | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.7 | 99.8 | 99.9 | 99.9 | |
| PATTERN FACTOR | 0.54 | 0.46 | 0.42 | 0.37 | |
| CO - EPAP CONTRIBUTION | 0.63 | 0.53 | 0.32 | 0.27 | |
| THC - EPAP CONTRIBUTION | 0.01 | 0.02 | 0.01 | 0.02 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | |
|---|------|------|------|-------|--|
| CO - E.I. | 2.01 | 1.91 | 0.61 | 0.38 | |
| THC - E.I. | 0.03 | 0.07 | 0.05 | 0.09 | |
| NO _x - E.I. | 36.2 | 23.9 | 24.0 | 26.0 | |
| COMBUSTION EFFICIENCY % | 100 | 100 | 100 | 100 | |
| CO - EPAP CONTRIBUTION | 0.11 | 0.11 | 0.03 | 0.02 | |
| THC - EPAP CONTRIBUTION | -0- | -0- | -0- | 0.005 | |
| NO _x - EPAP CONTRIBUTION. | 2.07 | 1.36 | 1.37 | 1.49 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-4

GE DOUBLE ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-4

1. TEST RIG DATA

| | | |
|-------------------------------|---------------|---|
| ENGINE CONDITION | IDLE | DATA NOT OBTAINED AT APPROACH, CLIMBOUT, TAKE-OFF OR CRUISE |
| READING NUMBER | I-1 | |
| FUELING MODE | PILOT ONLY | |
| INLET PRESSURE ATM. | 2.91 | |
| FUEL-AIR RATIO-PILOT | .0110 | |
| FUEL-AIR RATIO-TOTAL | .0110 | |
| CO - E.I. | 40.0 | |
| THC - E.I. | 7.0 | |
| NO _x - E.I. | 4.4 | |
| SMOKE NO. | ---- | |
| COMBUSTION EFFICIENCY % | 98.4 | |
| PATTERN FACTOR | 1.02 | |
| CO - EPAP CONTRIBUTION | 5.46 | |
| THC - EPAP CONTRIBUTION | 0.96 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | |
|---|------|--|
| CO - E.I. | 39.8 | |
| THC - E.I. | 7.0 | |
| NO _x - E.I. | 4.1 | |
| COMBUSTION EFFICIENCY % | 98.4 | |
| CO - EPAP CONTRIBUTION | 5.43 | |
| THC - EPAP CONTRIBUTION | 0.96 | |
| NO _x - EPAP CONTRIBUTION. | 0.56 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-5 .

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-5

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPR. | CLIMBOUT | | | TAKE-OFF | | NO CRUISE DATA OBTAINED |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|
| READING NUMBER | I-1 | APP-1 | CL-1 | CL-2 | CL-3 | TO-1 | TO-2 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.92 | 3.40 | 4.84 | 4.78 | 4.79 | 8.53 | 8.54 | |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0041 | .0060 | .0103 | .0054 | .0064 | |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0211 | .0208 | .0213 | .0231 | .0231 | |
| CO - E.I. | 39.5 | 45.6 | 8.6 | 9.4 | 22.1 | 2.0 | 2.2 | |
| THC - E.I. | 2.5 | 0.1 | -0- | -0- | 0.5 | 0.1 | 0.1 | |
| NO _x - E.I. | 4.0 | 6.7 | 7.2 | 7.8 | 12.9 | 12.5 | 13.1 | |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 98.8 | 98.9 | 99.8 | 99.8 | 99.4 | 100 | 99.9 | |
| PATTERN FACTOR | 0.87 | 1.34 | 0.38 | 0.31 | 0.47 | 0.34 | 0.36 | |
| CO - EPAP CONTRIBUTION | 5.39 | 4.16 | 1.28 | 1.40 | 3.29 | 0.11 | 0.13 | |
| THC - EPAP CONTRIBUTION | 0.33 | 0.01 | -0- | -0- | 0.07 | 0.006 | 0.006 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | |
|---|------|-------|------|------|------|-------|-------|--|
| CO - E.I. | 39.5 | 12.6 | 1.3 | 1.6 | 8.4 | 0.2 | 0.2 | |
| THC - E.I. | 2.5 | -0- | -0- | -0- | 0.1 | -0- | -0- | |
| NO _x - E.I. | 3.7 | 7.8 | 15.5 | 16.8 | 27.9 | 21.6 | 22.6 | |
| COMBUSTION EFFICIENCY % | 98.8 | 99.7 | 100 | 100 | 99.8 | 100 | 100 | |
| CO - EPAP CONTRIBUTION | 5.39 | 1.15 | 0.20 | 0.24 | 1.24 | 0.009 | 0.01 | |
| THC - EPAP CONTRIBUTION | 0.33 | 0.003 | -0- | -0- | 0.01 | 0.002 | 0.002 | |
| NO _x - EPAP CONTRIBUTION. | 0.50 | 0.71* | 2.31 | 2.50 | 4.15 | 1.23 | 1.29 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSUREORIGINAL PAGE IS
OF POOR QUALITY

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APPENDIX D-6

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-6

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | NO DATA OBTAINED AT CLIMBOUT, TAKEOFF OR CRUISE |
|-------------------------------|---------------|---------------|---|
| READING NUMBER | I-1 | APP-1 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | |
| INLET PRESSURE ATM. | 2.94 | 3.40 | |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | |
| CO - E.I. | 24.7 | 28.2 | |
| THC - E.I. | 2.1 | 0.1 | |
| NO _x - E.I. | 3.9 | 8.3 | |
| SMOKE NO. | 1. | 1. | |
| COMBUSTION EFFICIENCY % | 99.2 | 99.3 | |
| EATERER FACTOR | 0.95 | 1.16 | |
| CO - EPAP CONTRIBUTION | 3.37 | 2.57 | |
| THC - EPAP CONTRIBUTION | 0.29 | 0.01 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | |
|---|------|-------|--|
| CO - E.I. | 25.0 | 4.7 | |
| THC - E.I. | 2.1 | -0- | |
| NO _x - E.I. | 3.8 | 9.8* | |
| COMBUSTION EFFICIENCY % | 99.2 | 99.9 | |
| CO - EPAP CONTRIBUTION | 3.41 | 0.43 | |
| THC - EPAP CONTRIBUTION | 0.29 | 0.003 | |
| NO _x - EPAP CONTRIBUTION. | 0.51 | 0.89* | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX D-7

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-7

TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | CLIMBOUT | | | TAKE-OFF | | | | | | NO CRUISE OBTAINED |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-----------------------|
| READING NUMBER | I-1 | APP-1 | CL-1 | CL-2 | CL-3 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | TO-6 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.95 | 3.40 | 4.77 | 4.76 | 4.76 | 4.77 | 4.77 | 4.78 | 9.57 | 9.50 | 9.57 | |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0040 | .0058 | .0062 | .0040 | .0062 | .0104 | .0041 | .0061 | .0081 | |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0215 | .0220 | .0215 | .0230 | .0231 | .0233 | .0231 | .0231 | .0230 | |
| CO - E.I. | 18.5 | 75.9 | 10.5 | 6.9 | 8.8 | 5.7 | 4.1 | 7.3 | 2.7 | 3.3 | 2.2 | |
| THC - E.I. | 1.4 | 0.4 | 0.2 | 0.2 | 0.3 | 0.1 | 0.1 | 0.1 | -0- | 0.1 | -0- | |
| NO _x - E.I. | 3.5 | 7.0 | 5.3 | 4.9 | 5.0 | 5.3 | 4.8 | 7.8 | 10.9 | 9.4 | 10.5 | |
| SMOKE NO. | ---- | 0.6 | 0.2 | 0.3 | 0.2 | 0.5 | 0.8 | ---- | 0.5 | 1.7 | 0.9 | |
| COMBUSTION EFFICIENCY % | 99.4 | 98.2 | 99.7 | 99.8 | 99.8 | 99.9 | 99.9 | 99.8 | 99.9 | 99.9 | 100 | |
| PATTERN FACTOR | 1.14 | 1.07 | 0.56 | 0.41 | 0.38 | 0.46 | 0.45 | 0.46 | 0.49 | 0.51 | 0.31 | |
| CO - EPAP CONTRIBUTION | 2.53 | 6.92 | 1.56 | 1.03 | 1.31 | 0.33 | 0.23 | 0.42 | 0.15 | 0.19 | 0.13 | |
| THC - EPAP CONTRIBUTION | | | | | | | | | | | | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | |
|--|------|-------|-------|-------|-------|-------|-------|-------|------|-------|------|--|
| CO - E.I. | 18.9 | 30.9 | 2.0 | 0.8 | 1.4 | 0.4 | 0.1 | 0.7 | 0.3 | 0.3 | 0.2 | |
| THC - E.I. | 1.4 | 0.1 | 0.4 | 0.4 | 0.6 | -0- | -0- | -0- | -0- | -0- | -0- | |
| NO _x - E.I. | 3.5 | 9.0* | 12.5 | 10.8 | 11.6 | 13.2 | 12.0 | 19.0 | 19.0 | 15.9 | 18.3 | |
| COMBUSTION EFFICIENCY % | 99.4 | 99.3 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | |
| CO - EPAP CONTRIBUTION | 2.58 | 2.82 | 0.30 | 0.11 | 0.20 | 0.02 | 0.007 | 0.04 | 0.02 | 0.02 | 0.01 | |
| THC - EPAP CONTRIBUTION | 0.19 | 0.01 | 0.005 | 0.005 | 0.008 | 0.001 | 0.001 | 0.001 | -0- | 0.002 | -0- | |
| NO _x - EPAP CONTRIBUTION | 0.48 | 0.82* | 1.86 | 1.60 | 1.73 | 0.75 | 0.68 | 1.08 | 1.03 | 0.91 | 1.04 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{1/2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX D-8-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-8

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | | | | CLIMBOUT | | | | TAKE-OFF | |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | APP-6 | APP-7 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.94 | 3.39 | 3.39 | 3.40 | 3.41 | 6.80 | 6.80 | 6.81 | 4.76 | 4.76 | 4.76 | 4.76 | 4.76 | 4.76 |
| FUEL-AIR RATIO-PILOT | .0110 | .0137 | .0044 | .0056 | .0070 | .0046 | .0071 | .0092 | .0033 | .0042 | .0062 | .0081 | .0031 | .0042 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0137 | .0137 | .0139 | .0139 | .0140 | .0140 | .0140 | .0214 | .0213 | .0212 | .0213 | .0231 | .0231 |
| CO - E.I. | 18.5 | 21.2 | 14.1 | 12.3 | 10.8 | 11.9 | 91.7 | 69.9 | 6.9 | 4.8 | 4.4 | 7.0 | 4.6 | 2.8 |
| THC - E.I. | 1.7 | 0.5 | 51.3 | 50.1 | 52.0 | 30.6 | 37.0 | 37.6 | 0.1 | 0.1 | 0.1 | 0.3 | 0.1 | -0- |
| NO _x - E.I. | 3.2 | 6.4 | 2.2 | 2.8 | 3.5 | 3.8 | 4.8 | 5.6 | 6.5 | 6.6 | 7.7 | 8.3 | 8.0 | 8.1 |
| SMOKE NO. | 1. | 2. | ---- | 2. | ---- | 2. | ---- | ---- | ---- | ---- | 3. | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.4 | 99.5 | 91.6 | 92.1 | 92.3 | 94.2 | 94.2 | 94.6 | 99.8 | 99.9 | 99.9 | 99.8 | 99.9 | 99.9 |
| PATTERN FACTOR | 1.05 | 1.07 | 0.40 | 0.43 | 0.62 | 0.36 | 0.52 | 0.90 | 0.33 | 0.34 | 0.29 | 0.34 | 0.35 | 0.31 |
| CO - EPAP CONTRIBUTION | 2.53 | 1.93 | 12.84 | 11.22 | 9.84 | 10.87 | 8.36 | 6.37 | 1.03 | 0.71 | 0.65 | 1.04 | 0.26 | 0.16 |
| THC - EPAP CONTRIBUTION | 0.23 | 0.05 | 4.68 | 4.57 | 4.74 | 2.79 | 3.37 | 3.43 | 0.02 | 0.02 | 0.02 | 0.05 | 0.006 | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|--|------|-------|-------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|
| CO - E.I. | 18.7 | 2.4 | 11.6 | 99.3 | 85.4 | 108 | 81.7 | 60.8 | 0.8 | 0.3 | 0.2 | 0.8 | 0.2 | 0.1 |
| THC - E.I. | 1.7 | 0.1 | 14.9 | 14.6 | 15.2 | 17.8 | 21.5 | 21.9 | -0- | -0- | -0- | 0.1 | -0- | -0- |
| NO _x - E.I. | 3.1 | 8.5* | 4.3 | 5.5 | 6.8 | 4.9 | 6.3 | 7.3 | 14.8 | 15.1 | 17.7 | 20.1 | 19.5 | 19.5 |
| COMBUSTION EFFICIENCY % | 99.4 | 99.9 | 95.8 | 96.2 | 96.5 | 95.7 | 95.9 | 96.4 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 2.55 | 0.21 | 10.57 | 9.06 | 7.79 | 9.89 | 7.45 | 5.54 | 0.11 | 0.04 | 0.03 | 0.12 | 0.01 | 0.004 |
| THC - EPAP CONTRIBUTION | 0.23 | 0.01 | 1.36 | 1.33 | 1.38 | 1.62 | 1.96 | 2.00 | 0.003 | 0.003 | 0.003 | 0.009 | 0.001 | -0- |
| NO _x - EPAP CONTRIBUTION | 0.42 | 0.77* | 0.39 | 0.50 | 0.62 | 0.45 | 0.58 | 0.67 | 2.20 | 2.24 | 2.63 | 3.00 | 1.11 | 1.11 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX D-8-b

GE DOUBLE/ANNULAR CONFIGURATION D/A-8 cont.

. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | NO CRUISE DATA OBTAINED |
|-------------------------------|---------------------------------|-------------------------|
| READING NUMBER | TO-3 TO-4 | |
| FUELING MODE | PILOT PILOT & & MAIN MAIN | |
| INLET PRESSURE ATM. | 4.76 4.75 | |
| FUEL-AIR RATIO-PILOT | .0062 .0082 | |
| FUEL-AIR RATIO-TOTAL | .0231 .0231 | |
| CO - F.I. | 2.3 2.4 | |
| THC - E.I. | 0.1 0.1 | |
| NO _x - E.I. | 9.0 9.9 | |
| SMOKE NO. | 1. ---- | |
| COMBUSTION EFFICIENCY % | 99.9 99.9 | |
| PATTERN FACTOR | 0.27 0.30 | |
| CO - EPAP CONTRIBUTION | 0.13 0.14 | |
| THC - EPAP CONTRIBUTION | 0.006 0.006 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | |
|---|-------------|--|
| CO - E.I. | 0.06 0.06 | |
| THC - E.I. | 0.02 0.02 | |
| NO _x - E.I. | 21.67 24.30 | |
| COMBUSTION EFFICIENCY % | 100 100 | |
| CO - EPAP CONTRIBUTION | 0.003 0.003 | |
| THC - EPAP CONTRIBUTION | 0.001 0.001 | |
| NO _x - EPAP CONTRIBUTION. | 1.24 1.39 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-9-a.

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-9

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | | | | CLIMBOUT | | | TAKE-OFF | | |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | APP-6 | APP-7 | CL-1 | CL-2 | CL-3 | TO-1 | TO-2 | TO-3 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.91 | 3.39 | 3.40 | 3.39 | 3.38 | 3.40 | 3.41 | 3.41 | 4.76 | 4.76 | 4.78 | 4.76 | 4.76 | 4.76 |
| FUEL-AIR RATIO-PILOT | .0110 | .0139 | .0071 | .0091 | .0112 | .0072 | .0092 | .0113 | .0035 | .0041 | .0060 | .0030 | .0040 | .0060 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0139 | .0140 | .0140 | .0139 | .0140 | .0141 | .0141 | .0212 | .0210 | .0213 | .0225 | .0223 | .0227 |
| CO - E.I. | 21.2 | 18.6 | 113. | 89.0 | 72.5 | 68.3 | 63.5 | 53.4 | 7.3 | 5.4 | 3.9 | 5.8 | 3.6 | 2.5 |
| THC - E.I. | 3.0 | 0.4 | 55.7 | 52.6 | 38.2 | 25.5 | 23.0 | 21.8 | 0.1 | -0- | -0- | -0- | -0- | -0- |
| NO _x - E.I. | 3.2 | 6.4 | 3.4 | 4.2 | 5.1 | 3.9 | 4.8 | 5.5 | 5.8 | 6.0 | 7.0 | 7.2 | 7.2 | 8.0 |
| SMOKE NO. | 1. | 1. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 1. | ---- | 1. | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.2 | 99.5 | 91.8 | 92.7 | 94.5 | 95.9 | 96.2 | 96.6 | 99.8 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 |
| PATTERN FACTOR | 1.02 | 0.99 | 0.49 | 1.06 | 1.03 | 0.56 | 0.71 | 0.88 | 0.39 | 0.37 | 0.34 | 0.37 | 0.38 | 0.35 |
| CO - EPAP CONTRIBUTION | 2.89 | 1.70 | 10.26 | 8.12 | 6.61 | 6.23 | 5.79 | 4.87 | 1.09 | 0.80 | 0.58 | 0.33 | 0.21 | 0.14 |
| THC - EPAP CONTRIBUTION | 0.41 | 0.04 | 5.08 | 4.80 | 3.48 | 2.33 | 2.10 | 1.99 | 0.02 | -0- | -0- | -0- | -0- | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|---|------|-------|------|------|------|------|------|------|-------|------|------|------|-------|-------|
| CO - E.I. | 21.1 | 1.7 | 89.6 | 68.0 | 53.1 | 49.5 | 45.2 | 36.4 | 0.9 | 0.4 | 0.2 | 0.4 | 0.1 | 0.1 |
| THC - E.I. | 3.0 | 0.1 | 16.2 | 15.2 | 11.0 | 7.4 | 6.7 | 6.4 | -0- | -0- | -0- | -0- | -0- | -0- |
| NO _x - E.I. | 3.3 | 8.4* | 6.5 | 8.1 | 9.8 | 7.3 | 8.8 | 10.2 | 14.1 | 14.7 | 16.9 | 19.2 | 19.3 | 21.1 |
| COMBUSTION EFFICIENCY % | 99.2 | 100 | 96.3 | 96.9 | 97.7 | 98.1 | 98.3 | 98.5 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 2.88 | 0.11 | 8.17 | 6.20 | 4.84 | 4.51 | 4.12 | 3.32 | 0.13 | 0.06 | 0.02 | 0.02 | 0.005 | 0.003 |
| THC - EPAP CONTRIBUTION | 0.41 | 0.01 | 1.48 | 1.39 | 1.01 | 0.68 | 0.61 | 0.58 | 0.003 | -0- | -0- | -0- | -0- | -0- |
| NO _x - EPAP CONTRIBUTION. | 0.45 | 0.76* | 0.59 | 0.73 | 0.89 | 0.67 | 0.80 | 0.93 | 2.09 | 2.18 | 2.51 | 1.09 | 1.04 | 1.21 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

© -- ALTERNATE MAIN INJECTORS FUELED

APPENDIX D-9-b.

GE DOUBLE/ANNULAR CONFIGURATION D/A-9 cont.

1. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | CRUISE | | |
|-------------------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | TO-4 | CR-1 | CR-2 | CR-3 |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 4.76 | 4.78 | 4.66 | 4.66 |
| FUEL-AIR RATIO-PILOT | .0100 | .0032 | .0041 | .0062 |
| FUEL-AIR RATIO-TOTAL | .0227 | .0209 | .0209 | .0212 |
| CO - E.I. | 4.7 | 18.6 | 13.8 | 12.4 |
| THC - E.I. | -0- | 0.3 | 0.2 | 0.3 |
| NO _x - E.I. | 10.1 | 4.7 | 4.8 | 5.6 |
| SMOKE NO. | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.9 | 99.5 | 99.7 | 99.7 |
| PATTERN FACTOR | 0.31 | 0.38 | 0.36 | 0.28 |
| CO - EPAP CONTRIBUTION | 0.27 | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | -0- | ---- | ---- | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | |
|---|------|------|------|------|
| CO - E.I. | 0.2 | 10.6 | 6.7 | 5.7 |
| THC - E.I. | -0- | 0.1 | 0.1 | 0.1 |
| NO _x - E.I. | 26.5 | 7.4 | 8.3 | 8.9 |
| COMBUSTION EFFICIENCY % | 100 | 99.7 | 99.8 | 99.9 |
| CO - EPAP CONTRIBUTION | 0.01 | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | -0- | ---- | ---- | ---- |
| NO _x - EPAP CONTRIBUTION. | 1.52 | ---- | ---- | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-10-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A-10

TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | | | CLIMBOUT | | | | TAKE-OFF | | |
|-------------------------------|---------------|---------------|------------------------|------------------------|------------------------|------------------------|------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | APP-6 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 | TO-3 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.93 | 3.40 | 3.42 | 3.40 | 3.40 | 6.82 | 6.82 | 4.77 | 4.78 | 4.79 | 4.76 | 4.78 | 4.77 | 4.77 |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0040 | .0070 | .0103 | .0069 | .0107 | .0030 | .0042 | .0063 | .0080 | .0031 | .0041 | .0061 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0138 | .0138 | .0137 | .0142 | .0143 | .0208 | .0219 | .0202 | .0209 | .0227 | .0228 | .0228 |
| CO - E.I. | 17.8 | 19.5 | 92.7 | 65.5 | 53.3 | 49.6 | 36.8 | 13.6 | 10.2 | 9.7 | 14.2 | 7.2 | 4.9 | 4.0 |
| THC - E.I. | 1.4 | 0.3 | 53.5 | 30.5 | 24.6 | 21.8 | 15.7 | 0.1 | 0.1 | 0.1 | 0.3 | -0- | -0- | -0- |
| NO _x - E.I. | 3.3 | 6.6 | 2.4 | 3.8 | 5.2 | 5.0 | 7.2 | 6.2 | 6.2 | 7.2 | 7.9 | 7.5 | 7.7 | 8.6 |
| SMOKE NO. | 1. | 1. | --- | --- | --- | 1. | 1. | 1. | --- | --- | --- | 1. | --- | --- |
| COMBUSTION EFFICIENCY % | 99.4 | 99.5 | 92.5 | 95.4 | 96.3 | 96.7 | 97.6 | 99.7 | 99.8 | 99.8 | 99.6 | 99.8 | 99.9 | 99.9 |
| PATTERN FACTOR | 0.80 | 0.99 | 0.90 | 0.65 | 0.87 | 0.60 | 0.70 | 0.45 | 0.37 | 0.32 | 0.28 | 0.41 | 0.40 | 0.37 |
| CO - EPAP CONTRIBUTION | 2.43 | 1.78 | 8.45 | 5.97 | 4.86 | 4.52 | 3.36 | 2.02 | 1.52 | 1.44 | 2.11 | 0.41 | 0.28 | 0.23 |
| THC - EPAP CONTRIBUTION | 0.19 | 0.03 | 4.88 | 2.78 | 2.24 | 1.99 | 1.43 | 0.02 | 0.02 | 0.02 | 0.04 | -0- | -0- | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|--|------|-------|------|------|------|------|------|-------|-------|-------|-------|------|------|-------|
| CO - E.I. | 17.9 | 1.9 | 71.5 | 47.0 | 36.3 | 41.6 | 29.6 | 3.5 | 1.9 | 1.7 | 3.8 | 0.7 | 0.2 | 0.1 |
| THC - E.I. | 1.4 | -0- | 15.6 | 8.9 | 7.2 | 12.8 | 9.2 | -0- | -0- | -0- | 0.1 | -0- | -0- | -0- |
| NO _x - E.I. | 3.4 | 8.6* | 4.8 | 7.4 | 10.1 | 6.8 | 9.9 | 15.1 | 14.5 | 17.5 | 19.3 | 19.5 | 20.1 | 22.1 |
| COMBUSTION EFFICIENCY % | 99.4 | 100 | 96.8 | 98.0 | 98.4 | 97.7 | 98.4 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 2.44 | 0.17 | 6.52 | 4.29 | 3.31 | 3.79 | 2.70 | 0.51 | 0.29 | 0.26 | 0.56 | 0.04 | 0.01 | 0.007 |
| THC - EPAP CONTRIBUTION | 0.19 | -0- | 1.43 | 0.81 | 0.65 | 1.17 | 0.84 | 0.003 | 0.003 | 0.003 | 0.008 | -0- | -0- | -0- |
| NO _x - EPAP CONTRIBUTION | 0.46 | 0.78* | 0.44 | 0.67 | 0.92 | 0.62 | 0.90 | 2.24 | 2.15 | 2.61 | 2.88 | 1.11 | 1.15 | 1.26 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

@ -- ALTERNATE MAIN INJECTORS FUELED

APPENDIX D-10-b

GE DOUBLE/ANNULAR CONFIGURATION D/A-10 cont.

1. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | NO CRUISE DATA OBTAINED |
|-------------------------------|---------------------------------|-------------------------|
| READING NUMBER | TO-4 TO-5 | |
| FUELING MODE | PILOT PILOT & & MAIN MAIN | |
| INLET PRESSURE ATM. | 4.76 6.82 | |
| FUEL-AIR RATIO-PILOT | .0081 .0080 | |
| FUEL-AIR RATIO-TOTAL | .0229 .0229 | |
| CO - E.I. | 4.9 3.3 | |
| THC - E.I. | -0- -0- | |
| NO _x - E.I. | 9.1 13.6 | |
| SMOKE NO. | 1. 1. | |
| COMBUSTION EFFICIENCY % | 99.9 99.9 | |
| PATTERN FACTOR | 0.32 0.29 | |
| CO - EPAP CONTRIBUTION | 0.28 0.19 | |
| THC - EPAP CONTRIBUTION | -0- -0- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | |
|---|-------------|--|
| CO - E.I. | 0.24 0.17 | |
| THC - E.I. | -0- -0- | |
| NO _x - E.I. | 23.13 23.88 | |
| COMBUSTION EFFICIENCY % | 100 100 | |
| CO - EPAP CONTRIBUTION | 0.01 0.01 | |
| THC - EPAP CONTRIBUTION | -0- -0- | |
| NO _x - EPAP CONTRIBUTION. | 1.32 1.36 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-11-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A 11

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | | | | | | | CLIMBOUT | | |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|------------------------|------------------------|------------------------|------------------------|------------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | APP-6 | APP-7 | APP-8 | APP-9 | APP-10 | CL-1 | CL-2 | CL-3 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & 1/2 MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.91 | 3.42 | 3.40 | 3.41 | 3.42 | 6.80 | 3.40 | 3.39 | 3.40 | 6.80 | 6.79 | 4.76 | 4.76 | 4.78 |
| FUEL-AIR RATIO-PILOT | .0110 | .0138 | .0031 | .0070 | .0112 | .0035 | .0031 | .0070 | .0111 | .0070 | .0110 | .0033 | .0042 | .0061 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0138 | .0137 | .0138 | .0139 | .0138 | .0137 | .0139 | .0139 | .0139 | .0139 | .0214 | .0214 | .0212 |
| CO - E.I. | 20.6 | 18.4 | 14.0 | 105. | 68.1 | 90.5 | 54.5 | 23.5 | 17.7 | 16.0 | 36.2 | 4.4 | 3.0 | 2.7 |
| THC - E.I. | 2.5 | 0.1 | 35.8 | 45.4 | 30.2 | 14.1 | 12.8 | 2.5 | 14.2 | 1.8 | 10.7 | 0.1 | 0.1 | -0- |
| NO _x - E.I. | 3.0 | 6.6 | 1.7 | 2.9 | 4.9 | 2.2 | 3.0 | 4.4 | 5.7 | 5.9 | 7.8 | 6.4 | 6.9 | 7.9 |
| SMOKE NO. | 1. | 1. | ---- | ---- | ---- | ---- | 1. | 1. | 1. | ---- | ---- | ---- | 1. | ---- |
| COMBUSTION EFFICIENCY % | 99.3 | 99.6 | 93.1 | 93.0 | 95.4 | 95.2 | 97.4 | 99.2 | 97.5 | 99.4 | 98.1 | 99.9 | 99.9 | 99.9 |
| PATTERN FACTOR | 1.04 | 1.07 | 0.40 | 0.61 | 1.03 | 0.43 | 1.30 | 0.91 | 1.18 | 0.86 | 1.14 | 0.38 | 0.39 | 0.27 |
| CO - EPAP CONTRIBUTION | 2.81 | 1.68 | 12.80 | 9.58 | 6.21 | 8.25 | 4.97 | 2.14 | 4.35 | 1.46 | 3.30 | 0.65 | 0.45 | 0.40 |
| THC - EPAP CONTRIBUTION | 0.34 | 0.01 | 3.27 | 4.14 | 2.75 | 1.29 | 1.17 | 0.23 | 1.30 | 0.16 | 0.98 | 0.02 | 0.02 | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|--|------|-------|------|------|------|------|------|------|------|------|------|-------|-------|------|
| CO - E.I. | 20.5 | 1.7 | 116 | 82.7 | 49.3 | 80.6 | 37.3 | 11.8 | 31.5 | 10.8 | 29.0 | 0.2 | 0.1 | 0.1 |
| THC - E.I. | 2.5 | -0- | 10.4 | 13.2 | 8.8 | 8.2 | 3.7 | 0.7 | 4.1 | 1.1 | 6.3 | -0- | -0- | -0- |
| NO _x - E.I. | 3.2 | 8.6* | 3.3 | 5.5 | 9.1 | 2.8 | 5.9 | 8.1 | 10.7 | 7.7 | 10.3 | 15.1 | 15.8 | 18.4 |
| COMBUSTION EFFICIENCY % | 99.3 | 100 | 96.3 | 96.7 | 98.0 | 97.3 | 98.8 | 99.7 | 98.9 | 99.6 | 98.7 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 2.80 | 0.15 | 10.5 | 7.54 | 4.50 | 7.35 | 3.40 | 1.08 | 2.87 | 0.98 | 2.64 | 0.03 | 0.01 | 0.01 |
| THC - EPAP CONTRIBUTION | 0.34 | 0.003 | 0.95 | 1.21 | 0.80 | 0.75 | 0.34 | 0.07 | 0.38 | 0.10 | 0.57 | 0.003 | 0.003 | -0- |
| NO _x - EPAP CONTRIBUTION | 0.44 | 0.79* | 0.30 | 0.51 | 0.83 | 0.25 | 0.53 | 0.76 | 0.98 | 0.70 | 0.94 | 2.24 | 2.35 | 2.74 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS:

* -- $P^{.2}$ NO EXTRAPOLATION TO ENGINE PRESSURE
x

-- 15 INJECTOR SECTOR FUELED ON MAIN

APPENDIX D-11-b

GE DOUBLE/ANNULAR CONFIGURATION D/A -11 cont.

1. TEST RIG DATA

| ENGINE CONDITION | CLIMBOUT | TAKE-OFF | | | | | NO CRUISE DATA OBTAINED |
|-------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|
| READING NUMBER | CL-4 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 4.78 | 4.78 | 4.77 | 4.76 | 4.79 | 4.76 | |
| FUEL-AIR RATIO-PILOT | .0082 | .0031 | .0036 | .0041 | .0062 | .0082 | |
| FUEL-AIR RATIO-TOTAL | .0212 | .0228 | .0229 | .0229 | .0229 | .0230 | |
| CO - E.I. | 4.5 | 2.7 | 2.3 | 1.9 | 1.4 | 1.5 | |
| THC - E.I. | 0.1 | 0.1 | -0- | -0- | -0- | -0- | |
| NO _x - E.I. | 8.8 | 7.8 | 8.0 | 8.0 | 8.9 | 9.6 | |
| SMOKE NO. | ---- | ---- | 1. | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.9 | 99.9 | 100 | 100 | 100 | 100 | |
| PATTERN FACTOR | 0.30 | 0.40 | 0.44 | 0.38 | 0.29 | 0.25 | |
| CO - EPAP CONTRIBUTION | 0.67 | 0.15 | 0.13 | 0.11 | 0.08 | 0.09 | |
| THC - EPAP CONTRIBUTION | 0.02 | 0.006 | -0- | -0- | -0- | -0- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | 0.23 | 0.07 | 0.06 | 0.05 | 0.04 | 0.04 | |
|--|-------|-------|-------|-------|-------|-------|--|
| THC - E.I. | 0.02 | 0.02 | -0- | -0- | -0- | -0- | |
| NO _x - E.I. | 20.32 | 19.76 | 20.79 | 20.98 | 23.60 | 25.00 | |
| COMBUSTION EFFICIENCY % | 100 | 100 | 100 | 100 | 100 | 100 | |
| CO - EPAP CONTRIBUTION | 0.03 | 0.004 | 0.003 | 0.003 | 0.002 | 0.002 | |
| THC - EPAP CONTRIBUTION | 0.003 | 0.001 | -0- | -0- | -0- | -0- | |
| NO _x - EPAP CONTRIBUTION | 3.02 | 1.13 | 1.19 | 1.20 | 1.35 | 1.43 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

-- 15 INJECTOR SECTOR FUELED ON MAIN

APPENDIX D-12 -a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATIONS D/A 12 a & b

1. TEST RIG DATA

| ENGINE CONDITION | IDLE 12-a | IDLE | APPROACH | | | | | CLIMBOUT | | | | | TAKE-OFF | |
|-------------------------------|---------------|---------------|---------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | I-2 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | CL-1 | CL-2 | CL-3 | CL-4 | CL-5 | TO-1 | TO-2 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & $\frac{1}{2}$ MAIN | PILOT & $\frac{1}{2}$ MAIN | PILOT & $\frac{1}{2}$ MAIN | PILOT & $\frac{1}{2}$ MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.93 | 2.94 | 3.41 | 6.75 | 6.77 | 6.80 | 6.78 | 4.76 | 4.76 | 4.77 | 4.77 | 4.76 | 4.77 | 4.78 |
| FUEL-AIR RATIO-PILOT | .0110 | .0110 | .0143 | .0057 | .0072 | .0092 | .0112 | .0025 | .0031 | .0041 | .0062 | .0083 | .0032 | .0036 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0110 | .0143 | .0143 | .0142 | .0142 | .0141 | .0216 | .0213 | .0215 | .0215 | .0216 | .0236 | .0233 |
| CO - E.I. | 25.0 | 21.7 | 24.7 | 16.0 | 20.9 | 37.4 | 40.3 | 8.9 | 7.2 | 4.6 | 4.0 | 6.5 | 4.4 | 3.3 |
| THC - E.I. | 7.1 | 2.8 | 0.3 | 2.4 | 2.7 | 6.6 | 13.8 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | -0- |
| NO _x - E.I. | 3.4 | 3.0 | 6.5 | 5.3 | 5.9 | 6.7 | 7.6 | 6.5 | 6.5 | 6.6 | 7.5 | 8.4 | 7.6 | 7.5 |
| SMOKE NO. | 1. | 1. | 1. | 3. | 2. | 2. | 3. | 1. | --- | --- | --- | --- | --- | 1. |
| COMBUSTION EFFICIENCY % | 98.7 | 99.2 | 99.4 | 99.4 | 99.3 | 98.5 | 97.7 | 99.8 | 99.8 | 99.9 | 99.9 | 99.8 | 99.9 | 99.9 |
| PATTERN FACTOR | 1.16 | 1.27 | 1.05 | 1.16 | 1.02 | 0.86 | 1.04 | 0.41 | 0.33 | 0.36 | 0.34 | 0.34 | 0.41 | 0.38 |
| CO - EPAP CONTRIBUTION | 3.41 | 2.96 | 2.25 | 1.46 | 1.91 | 3.41 | 3.68 | 1.32 | 1.07 | 0.68 | 0.59 | 0.97 | 0.25 | 0.19 |
| THC - EPAP CONTRIBUTION | 0.97 | 0.38 | 0.03 | 0.22 | 0.25 | 0.60 | 1.26 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|--|------|------|-------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| CO - E.I. | 25.2 | 22.0 | 3.5 | 10.8 | 15.1 | 30.1 | 32.8 | 1.4 | 0.9 | 0.3 | 0.2 | 0.7 | 0.2 | 0.1 |
| THC - E.I. | 7.1 | 2.8 | 0.1 | 1.4 | 1.6 | 3.8 | 8.0 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.06 | -0- |
| NO _x - E.I. | 3.4 | 3.2 | 8.8* | 6.9 | 7.7 | 8.8 | 10.0 | 15.8 | 14.7 | 14.8 | 17.5 | 21.9 | 19.8 | 20.1 |
| COMBUSTION EFFICIENCY % | 98.7 | 99.2 | 99.9 | 99.6 | 99.5 | 98.9 | 98.4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 3.44 | 3.00 | 0.31 | 0.98 | 1.37 | 2.75 | 2.99 | 0.21 | 0.13 | 0.04 | 0.02 | 0.10 | 0.01 | 0.005 |
| THC - EPAP CONTRIBUTION | 0.97 | 0.39 | 0.008 | 0.13 | 0.14 | 0.35 | 0.73 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.003 | -0- |
| NO _x - EPAP CONTRIBUTION | 0.46 | 0.43 | 0.80* | 0.63 | 0.71 | 0.80 | 0.91 | 2.34 | 2.18 | 2.20 | 2.61 | 3.26 | 1.13 | 1.15 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

-- 15 INJECTOR SECTOR FUELED ON MAIN

APPENDIX D-12-b

GE DOUBLE/ANNULAR CONFIGURATION D/A-12-b cont.

1. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | | | NO CRUISE DATA OBTAINED |
|-------------------------------|--------------------|--------------------|--------------------|-------------------------|
| REAR FUELING NUMBER | TO-3 | TO-4 | TO-5 | |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 4.77 | 4.78 | 4.78 | |
| FUEL-AIR RATIO-PILOT | .0042 | .0062 | .0082 | |
| FUEL-AIR RATIO-TOTAL | .0236 | .0234 | .0234 | |
| CO - E.I. | 2.9 | 2.0 | 2.1 | |
| THC - E.I. | 0.1 | 0.1 | -0- | |
| NO _x - E.I. | 7.5 | 8.4 | 9.4 | |
| SMOKE NO. | ---- | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 99.9 | 100 | 100 | |
| PATTERN FACTOR | 0.35 | 0.35 | 0.35 | |
| CO - EPAP CONTRIBUTION | 0.17 | 0.11 | 0.12 | |
| THC - EPAP CONTRIBUTION | 0.006 | 0.006 | -0- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | 0.07 | 0.05 | 0.05 | |
|---|-------|-------|-------|--|
| THC - E.I. | 0.02 | 0.02 | -0- | |
| NO _x - E.I. | 19.33 | 22.42 | 24.88 | |
| COMBUSTION EFFICIENCY % | 100 | 100 | 100 | |
| CO - EPAP CONTRIBUTION | .0004 | 0.003 | 0.003 | |
| THC - EPAP CONTRIBUTION | -0- | -0- | -0- | |
| NO _x - EPAP CONTRIBUTION. | 1.10 | 1.28 | 1.42 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-13-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A 13

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | | CLIMBOUT | | | | TAKE-OFF | | | |
|-------------------------------|---------------|---------------|---------------|----------------------------------|----------------------------------|----------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | I-1 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 | TO-3 | TO-4 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & $\frac{1}{2}$ MAIN | PILOT & $\frac{1}{2}$ MAIN | PILOT & $\frac{1}{2}$ MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.93 | 3.45 | 6.84 | 6.80 | 6.82 | 6.83 | 4.72 | 4.74 | 4.75 | 4.73 | 2.72 | 4.76 | 4.72 | 4.72 |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0140 | .0030 | .0060 | .0085 | .0030 | .0041 | .0061 | .0082 | .0063 | .0025 | .0036 | .0038 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0140 | .0140 | .0141 | .0139 | .0210 | .0212 | .0212 | .0214 | .0232 | .0233 | .0231 | .0234 |
| CO - E.I. | 19.2 | 23.4 | 9.7 | 47.7 | 16.8 | 28.5 | 10.7 | 5.5 | 4.4 | 7.0 | 5.2 | 8.2 | 4.9 | 4.9 |
| THC - E.I. | 2.2 | 0.1 | 0.1 | 12.8 | 4.1 | 4.4 | 0.1 | -0- | -0- | 0.1 | -0- | -0- | -0- | -0- |
| NO _x - E.I. | 3.1 | 6.3 | 8.3 | 4.3 | 4.6 | 5.7 | 5.3 | 5.3 | 6.1 | 6.9 | 5.6 | 7.1 | 6.8 | 6.9 |
| SMOKE NO. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.3 | 99.4 | 99.8 | 97.6 | 99.2 | 98.9 | 99.7 | 99.9 | 99.9 | 99.8 | 99.9 | 99.8 | 99.8 | 99.9 |
| EATERR FACTOR | 1.19 | 1.16 | 1.20 | 1.40 | 0.98 | 0.75 | 0.40 | 0.41 | 0.36 | 0.28 | ---- | 0.51 | 0.43 | 0.43 |
| CO - EPAP CONTRIBUTION | 2.62 | 2.13 | 0.88 | 4.35 | 1.53 | 2.60 | 1.59 | 0.82 | 0.65 | 1.04 | 0.30 | 0.47 | 0.28 | 0.28 |
| THC - EPAP CONTRIBUTION | 0.30 | 0.01 | 0.01 | 1.17 | 0.37 | 0.40 | 0.01 | -0- | -0- | 0.01 | -0- | -0- | -0- | -0- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|--|------|-------|-------|------|------|------|-------|------|------|-------|-------|------|------|------|
| CO - E.I. | 19.3 | 3.1 | 3.3 | 39.8 | 11.5 | 22.0 | 2.1 | 0.4 | 0.2 | 0.8 | 0.1 | 1.0 | 0.2 | 0.2 |
| THC - E.I. | 2.2 | -0- | 0.1 | 7.4 | 2.4 | 2.6 | -0- | -0- | -0- | -0- | -0- | -0- | -0- | -0- |
| NO _x - E.I. | 3.0 | 8.9* | 8.8* | 6.0 | 6.3 | 8.0 | 13.8 | 13.3 | 14.9 | 17.4 | 19.4 | 18.6 | 18.6 | 18.9 |
| COMBUSTION EFFICIENCY % | 99.3 | 99.9 | 99.9 | 98.3 | 99.5 | 99.2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 2.64 | 0.28 | 0.30 | 3.63 | 1.05 | 2.01 | 0.31 | 0.06 | 0.03 | 0.12 | 0.007 | 0.06 | 0.01 | 0.01 |
| THC - EPAP CONTRIBUTION | 0.30 | 0.003 | 0.005 | 0.68 | 0.22 | 0.23 | 0.003 | -0- | -0- | 0.003 | -0- | -0- | -0- | -0- |
| NO _x - EPAP CONTRIBUTION | 0.41 | 0.81* | 0.80* | 0.55 | 0.57 | 0.73 | 2.05 | 1.97 | 2.22 | 2.59 | 1.11 | 1.06 | 1.06 | 1.08 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- $P^{0.2}$ NO_x EXTRAPOLATION TO ENGINE PRESSURE

-- 15 INJECTOR SECTOR FUELED ON MAIN

APPENDIX D-13-b

GE DOUBLE/ANNULAR CONFIGURATION D/A-13 cont.

1. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | | | | | | | NO CRUISE DATA OBTAINED |
|-------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|
| READING NUMBER | TO-5 | TO-6 | TO-7 | TO-8 | TO-9 | TO-10 | TO-11 | |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 4.75 | 4.73 | 6.83 | 9.55 | 9.53 | 9.53 | 9.54 | |
| FUEL-AIR RATIO-PILOT | .0047 | 0..62 | .0060 | .0025 | .0036 | .0045 | .0060 | |
| FUEL-AIR RATIO-TOTAL | .0235 | .0232 | .0228 | .0229 | .0231 | .0231 | .0229 | |
| CO - E.I. | 3.4 | 2.4 | 1.4 | 4.2 | 2.2 | 1.4 | 1.0 | |
| THC - E.I. | -0- | -0- | -0- | 0.2 | -0- | -0- | -0- | |
| NO _x - E.I. | 6.8 | 7.3 | 9.2 | 9.0 | 9.7 | 9.7 | 10.2 | |
| SMOKE NO. | ----- | ----- | ----- | ----- | ----- | ----- | ----- | |
| COMBUSTION EFFICIENCY % | 99.9 | 99.9 | 100 | 99.9 | 99.9 | 100 | 100 | |
| PATTERN FACTOR | 0.43 | 0.36 | 0.32 | 0.42 | 0.38 | 0.31 | 0.32 | |
| CO - EPAP CONTRIBUTION | 0.19 | 0.14 | 0.08 | 0.24 | 0.13 | 0.03 | 0.06 | |
| THC - EPAP CONTRIBUTION | -0- | -0- | -0- | 0.01 | -0- | -0- | -0- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | 0.09 | 0.06 | 0.07 | 0.52 | 0.22 | 0.14 | 0.10 |
|---|-------|-------|-------|-------|------|-------|-------|
| THC - E.I. | -0- | -0- | -0- | 0.06 | -0- | -0- | -0- |
| NO _x - E.I. | 18.3 | 20.3 | 20.3 | 16.9 | 18.2 | 18.3 | 19.1 |
| COMBUSTION EFFICIENCY % | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 0.005 | 0.003 | 0.004 | 0.03 | 0.01 | 0.008 | 0.006 |
| THC - EPAP CONTRIBUTION | -0- | -0- | -0- | 0.003 | -0- | -0- | -0- |
| NO _x - EPAP CONTRIBUTION. | 1.04 | 1.16 | 1.16 | 0.96 | 1.04 | 1.04 | 1.09 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX D-14-a

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A 14-a

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | | CLIMBOUT | | | | TAKE-OFF | | | |
|-------------------------------|---------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | ID-1 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 | TO-3 | TO-4 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.91 | 3.41 | 6.80 | 6.80 | 6.80 | 6.80 | 9.53 | 9.51 | 9.53 | 9.54 | 9.56 | 9.60 | 9.54 | 9.53 |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0140 | .0031 | .0062 | .0091 | .0025 | .0031 | .0041 | .0062 | .0021 | .0031 | .0042 | .0063 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0140 | .0141 | .0142 | .0141 | .0217 | .0216 | .0217 | .0217 | .0234 | .0234 | .0236 | .0235 |
| CO - E.I. | 26.9 | 22.4 | 11.2 | 101. | 87.7 | 71.5 | 6.0 | 4.4 | 3.0 | 2.4 | 6.4 | 4.3 | 2.4 | 1.9 |
| THC - E.I. | 3.8 | 0.7 | 0.5 | 22.0 | 28.5 | 32.4 | 0.1 | -0- | -0- | -0- | 0.2 | 0.1 | 0.1 | 0.1 |
| NO _x - E.I. | 3.0 | 5.8 | 7.6 | 3.5 | 4.9 | 5.7 | 10.4 | 10.4 | 10.7 | 11.8 | 12.2 | 12.1 | 12.5 | 13.4 |
| SMOKE NO. | 1. | 1. | -0- | ---- | ---- | ---- | ---- | ---- | 1. | ---- | ---- | -0- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.0 | 99.4 | 99.7 | 95.4 | 95.1 | 94.4 | 99.9 | 99.9 | 99.9 | 99.9 | 99.8 | 99.9 | 99.9 | 100 |
| PATTERN FACTOR | 1.10 | 1.15 | 1.35 | 0.58 | 0.58 | 0.89 | 0.50 | 0.47 | 0.45 | 0.40 | 0.58 | 0.57 | 0.52 | 0.44 |
| CO - EPAP CONTRIBUTION | 3.67 | 2.06 | 1.03 | 9.28 | 8.05 | 6.57 | 0.89 | 0.65 | 0.45 | 0.36 | 0.37 | 0.25 | 0.14 | 0.11 |
| THC - EPAP CONTRIBUTION | 0.52 | 0.06 | 0.04 | 2.01 | 2.60 | 3.59 | 0.01 | -0- | -0- | -0- | 0.01 | 0.006 | 0.006 | 0.006 |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|---|------|-------|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|
| CO - E.I. | 26.8 | 2.7 | 3.8 | 101. | 77.9 | 62.3 | 1.4 | 0.7 | 0.4 | 0.3 | 1.4 | 0.6 | 0.3 | 0.2 |
| THC - E.I. | 3.0 | 0.2 | 0.3 | 12.8 | 16.6 | 22.9 | 0.04 | -0- | -0- | -0- | 0.06 | 0.03 | 0.03 | 0.03 |
| NO _x - E.I. | 3.2 | 7.6* | 8.4* | 4.7 | 6.5 | 7.7 | 17.01 | 16.99 | 17.58 | 19.12 | 21.48 | 21.41 | 20.96 | 22.41 |
| COMBUSTION EFFICIENCY % | 99.1 | 99.9 | 99.9 | 96.4 | 96.5 | 96.3 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CO - EPAP CONTRIBUTION | 3.66 | 0.25 | 0.35 | 9.25 | 7.15 | 5.72 | 0.21 | 0.11 | 0.06 | 0.05 | 0.08 | 0.03 | 0.01 | 0.01 |
| THC - EPAP CONTRIBUTION | 0.41 | 0.02 | 0.02 | 1.17 | 1.51 | 2.09 | 0.006 | -0- | -0- | -0- | 0.003 | 0.002 | 0.002 | 0.002 |
| NO _x - EPAP CONTRIBUTION. | 0.44 | 0.69* | 0.77* | 0.43 | 0.59 | 0.71 | 2.53 | 2.53 | 2.61 | 2.84 | 1.23 | 1.22 | 1.20 | 1.28 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX D-14-b .

GE DOUBLE/ANNULAR CONFIGURATION D/A-14-a cont.

1. TEST RIG DATA

| ENGINE CONDITION | CRUISE | | | |
|-------------------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | CR-1 | CR-2 | CR-3 | CR-4 |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 4.76 | 4.76 | 4.78 | 4.78 |
| FUEL-AIR RATIO-PILOT | .0031 | .0042 | .0062 | .0083 |
| FUEL-AIR RATIO-TOTAL | .0214 | .0213 | .0213 | .0213 |
| CO - E.I. | 16.4 | 11.5 | 10.7 | 13.9 |
| THC - E.I. | 0.4 | 0.2 | 0.2 | 0.4 |
| NO _x - E.I. | 5.1 | 5.2 | 6.2 | 7.0 |
| SMOKE NO. | ---- | 1. | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.6 | 99.7 | 99.7 | 99.6 |
| PATTERN FACTOR | 0.51 | 0.50 | 0.50 | 0.56 |
| CO - EPAP CONTRIBUTION | ---- | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | ---- | ---- | ---- | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | |
|---|------|------|------|------|
| CO - E.I. | 8.8 | 5.2 | 4.6 | 6.9 |
| THC - E.I. | 0.2 | 0.1 | 0.1 | 0.2 |
| NO _x - E.I. | 8.3 | 8.6 | 9.9 | 11.1 |
| COMBUSTION EFFICIENCY % | 99.8 | 99.9 | 99.9 | 99.8 |
| CO - EPAP CONTRIBUTION | ---- | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | ---- | ---- | ---- | ---- |
| NO _x - EPAP CONTRIBUTION. | ---- | ---- | ---- | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

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APPENDIX D-15 .

GE DOUBLE/ANNULAR COMBUSTOR DATA, CONFIGURATION D/A 14-b

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | NO CLIMBOUT, TAKE-OFF OR CRUISE DATA OBTAINED |
|-------------------------------|---------------|---------------|---------------|---------------|---|
| READING NUMBER | ID-1 | APP-1 | APP-2 | APP-3 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | |
| INLET PRESSURE ATM. | 2.93 | 3.40 | 5.08 | 6.77 | |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0140 | .0140 | |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0140 | .0140 | |
| CO - E.I. | 47.0 | 32.5 | 20.5 | 15.4 | |
| THC - E.I. | 19.4 | 0.3 | 0.1 | 0.2 | |
| NO _x - E.I. | 3.1 | 6.1 | 7.5 | 8.0 | |
| SMOKE NO. | 1. | 1. | 1. | 1. | |
| COMBUSTION EFFICIENCY % | 97.0 | 99.2 | 99.5 | 99.6 | |
| PATTERN FACTOR | 1.68 | 1.30 | 1.23 | 1.45 | |
| CO - EPAP CONTRIBUTION | 6.42 | 2.96 | 1.87 | 1.40 | |
| THC - EPAP CONTRIBUTION | 2.65 | 0.03 | 0.01 | 0.02 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | |
|--|------|-------|-------|-------|--|
| CO - E.I. | 47.2 | 6.4 | 4.5 | 5.2 | |
| THC - E.I. | 19.5 | 0.1 | 0.04 | 0.1 | |
| NO _x - E.I. | 3.1 | 8.2* | 8.8* | 8.9* | |
| COMBUSTION EFFICIENCY % | 96.9 | 99.8 | 99.9 | 99.9 | |
| CO - EPAP CONTRIBUTION | 6.45 | 0.58 | 0.41 | 0.47 | |
| THC - EPAP CONTRIBUTION | 2.66 | 0.008 | 0.004 | 0.011 | |
| NO _x - EPAP CONTRIBUTION | 0.42 | 0.75* | 0.80* | 0.82* | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX E

This appendix contains summaries of test rig data for all of the General Electric radial/axial combustor configurations evaluated in Phase II of the Experimental Clean Combustor Program. Data are presented in two groupings:

1. Test Rig Data - In this section, data are presented as they were obtained in the test rig with one exception. In setting test point conditions, it was rarely possible to operate precisely at the design point fuel-air ratio. Thus, when more than fuel-air ratio was investigated at a test condition, the general procedure used was to plot the emissions against fuel-air ratio and determine emission levels at the design point fuel-air ratio by interpolation. When only one fuel-air ratio was investigated at a test condition, emission levels at that value are reported.

2. Data Corrected to Engine Pressures - Correlations which were used to extrapolate test rig data to engine conditions are contained in the Data Correlation Procedures section of the report. Calculations of EPAP values were made according to the procedures described in the EPAP Calculations section of the report.

APPENDIX E-1-a

GE RADIAL/AXIAL COMBUSTOR DATA, CONFIGURATION R/A-1

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | | APPROACH | | | | | | | | | | | CLIMBOUT | |
|-------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|--|
| READING NUMBER | ID-1 | ID-2 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | APP-6 | APP-7 | APP-8 | APP-9 | APP-10 | CL-1 | CL-2 | |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | |
| INLET PRESSURE ATM. | 2.91 | 2.89 | 3.42 | 3.42 | 6.85 | 3.42 | 6.87 | 3.42 | 3.42 | 6.83 | 6.87 | 3.40 | 4.76 | 4.75 | |
| FUEL-AIR RATIO-PILOT | .0110 | .0115 | .0137 | .0138 | .0139 | .0038 | .0058 | .0059 | .0057 | .0057 | .0073 | .0074 | .0047 | .0057 | |
| FUEL-AIR RATIO-TOTAL | .0110 | .0115 | .0137 | .0138 | .0139 | .0137 | .0137 | .0139 | .0137 | .0138 | .0138 | .0139 | .0208 | .0206 | |
| CO - E.I. | 91.0 | 86.8 | 29.6 | 27.9 | 11.6 | 106. | 87.2 | 97.0 | 111. | 101. | 99.7 | 107. | 64.9 | 54.2 | |
| THC - E.I. | 34.0 | 29.1 | 2.5 | 0.5 | 0.4 | 170. | 73.0 | 87.2 | 155. | 100. | 69.0 | 93.9 | 13.8 | 6.7 | |
| NO _x - E.I. | 2.1 | 2.3 | 4.4 | 5.3 | 6.3 | 2.3 | 4.0 | 3.2 | 2.7 | 4.0 | 6.1 | 4.5 | 5.1 | 7.4 | |
| SMOKE NO. | 5.9 | 10.4 | --- | --- | --- | --- | --- | 1.6 | --- | --- | --- | --- | --- | --- | |
| COMBUSTION EFFICIENCY % | 94.5 | 95.1 | 99.1 | 99.3 | 99.7 | 80.6 | 90.7 | 89.0 | 81.9 | 87.6 | 90.8 | 88.1 | 97.1 | 98.1 | |
| PATTERN FACTOR | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |
| CO - EPAP CONTRIBUTION | 12.43 | 11.85 | 2.70 | 2.54 | 1.06 | 9.67 | 7.95 | 8.95 | 10.12 | 9.19 | 9.09 | 9.76 | 9.65 | 8.06 | |
| THC - EPAP CONTRIBUTION | 4.64 | 3.97 | 0.23 | 0.05 | 0.04 | 15.47 | 6.66 | 7.95 | 14.14 | 9.15 | 6.29 | 8.56 | 2.05 | 1.00 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | 90.8 | 86.2 | 5.3 | 4.6 | 2.7 | 83.7 | 77.6 | 75.5 | 88.3 | 85.4 | 89.6 | 76.6 | 41.0 | 32.2 |
|--|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|
| THC - E.I. | 33.9 | 28.8 | 0.7 | 0.2 | 0.2 | 49.6 | 42.9 | 25.5 | 45.3 | 58.6 | 40.5 | 27.3 | 2.5 | 1.2 |
| NO _x - E.I. | 2.1 | 2.0 | 5.5* | 6.4* | 6.9* | 4.4 | 5.3 | 5.9 | 5.2 | 5.3 | 8.1 | 8.5 | 11.5 | 16.9 |
| COMBUSTION EFFICIENCY % | 94.5 | 95.1 | 99.8 | 99.9 | 99.9 | 93.1 | 93.9 | 95.7 | 93.4 | 92.1 | 93.9 | 95.5 | 98.8 | 99.1 |
| CO - EPAP CONTRIBUTION | 12.40 | 11.77 | 0.48 | 0.42 | 0.25 | 7.73 | 7.07 | 6.88 | 8.05 | 7.79 | 8.17 | 6.98 | 6.10 | 4.79 |
| THC - EPAP CONTRIBUTION | 4.63 | 3.93 | 0.07 | 0.01 | 0.02 | 4.52 | 3.91 | 2.33 | 4.13 | 5.34 | 3.69 | 2.49 | 0.38 | 0.18 |
| NO _x - EPAP CONTRIBUTION | 0.28 | 0.31 | 0.50* | 0.58* | 0.63* | 0.40 | 0.48 | 0.54 | 0.40 | 0.49 | 0.73 | 0.77 | 1.71 | 2.52 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

† -- ALTERNATE PILOT INJECTORS FUELED

+ -- ALTERNATE PILOT AND ALTERNATE MAIN INJECTORS FUELED

@ -- ALTERNATE MAIN INJECTORS FUELED

APPENDIX E-1-b

GE RADIAL/AXIAL CONFIGURATION R/A-1 cont.

1. TEST RIG DATA

| ENGINE CONDITION | CLIMBOUT | TAKE-OFF | | | | | | | | NO CRUISE DATA OBTAINED |
|-------------------------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|
| READING NUMBER | CL-3 | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | TO-6 | TO-7 | TO-8 | |
| FUELING MODE | PILOT MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 4.75 | 9.59 | 4.72 | 9.59 | 4.78 | 4.75 | 4.080 | 4.79 | 4.80 | |
| FUEL-AIR RATIO-PILOT | .0068 | .0038 | .0038 | .0057 | .0058 | .0077 | .0030 | .0038 | .0049 | |
| FUEL-AIR RATIO-TOTAL | .0209 | .0225 | .0231 | .0222 | .0228 | .0226 | .0229 | .0228 | .0231 | |
| CO - E.I. | 38.0 | 23.1 | 31.7 | 13.7 | 16.9 | 13.3 | 53.0 | 38.4 | 28.9 | |
| THC - E.I. | 2.4 | 1.5 | 3.4 | 0.2 | 0.4 | 0.2 | 24.0 | 9.2 | 3.8 | |
| NO _x - E.I. | 10.5 | 7.0 | 4.9 | 12.7 | 9.8 | 14.0 | 5.3 | 7.4 | 8.4 | |
| SMOKE NO. | ---- | ---- | 1.7 | ---- | ---- | ---- | ---- | 0.5 | ---- | |
| COMBUSTION EFFICIENCY % | 98.9 | 99.3 | 98.9 | 99.7 | 99.6 | 99.2 | 96.4 | 98.2 | 98.9 | |
| EATERR FACTOR | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| CO - EPAP CONTRIBUTION | 5.65 | 1.32 | 1.81 | 0.78 | 0.97 | 0.76 | 3.03 | 2.19 | 1.65 | |
| THC - EPAP CONTRIBUTION | 0.36 | 0.09 | 0.19 | 0.01 | 0.02 | 0.01 | 1.37 | 0.53 | 0.22 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| CO - E.I. | 19.5 | 12.3 | 13.9 | 5.5 | 4.7 | 3.0 | 30.0 | 18.8 | 12.1 | |
|---|------|------|------|------|------|------|------|------|------|--|
| THC - E.I. | 0.4 | 0.5 | 0.5 | 0.06 | 0.06 | 0.03 | 3.9 | 1.5 | 0.6 | |
| NO _x - E.I. | 23.3 | 12.0 | 11.7 | 21.8 | 23.4 | 33.1 | 12.5 | 17.4 | 19.5 | |
| COMBUSTION EFFICIENCY % | 99.5 | 99.7 | 99.6 | 99.9 | 99.9 | 99.9 | 98.9 | 99.4 | 99.7 | |
| CO - EPAP CONTRIBUTION | 2.90 | 0.70 | 0.79 | 0.31 | 0.27 | 0.17 | 1.71 | 1.07 | 0.69 | |
| THC - EPAP CONTRIBUTION | 0.07 | 0.03 | 0.03 | -0- | -0- | -0- | 6.22 | 0.08 | 0.03 | |
| NO _x - EPAP CONTRIBUTION. | 3.47 | 0.69 | 0.67 | 1.24 | 1.34 | 1.89 | 0.71 | 0.99 | 1.11 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- ALTERNATE PILOT INJECTORS FUELED

APPENDIX E-2-a

GE RADIAL/AXIAL COMBUSTOR DATA, CONFIGURATION R/A-2

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | | | | | CLIMBOUT | | | TAKE-OFF | | |
|-------------------------------|---------------|---------------|-----------------------------------|-----------------------------------|-----------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-----------------------------------|---------------------------------|--------------------|--------------------|
| READING NUMBER | ID-1 | APP-1 | APP-2 | APP-3 | APP-4 | APP-5 | APP-6 | APP-7 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT [@] & ½ MAIN | PILOT [@] & ½ MAIN | PILOT [@] & ½ MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT [@] & ½ MAIN | PILOT [@] & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.91 | 4.78 | 4.77 | 4.80 | 4.74 | 4.78 | 4.80 | 4.79 | 4.55 | 4.76 | 4.76 | 4.74 | 4.80 | 4.60 |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0048 | .0057 | .0077 | .0040 | .0050 | .0060 | .0049 | .0074 | .0049 | .0074 | .0039 | .0048 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0137 | .0137 | .0142 | .0142 | .0143 | .0141 | .0215 | .0215 | .0215 | .0215 | .0227 | .0230 |
| CO - E.I. | 54.0 | 12.5 | 99.8 | 91.9 | 83.4 | 127. | 117. | 111. | 26.4 | 19.0 | 27.3 | 21.1 | 23.3 | 15.4 |
| THC - E.I. | 6.1 | 0.4 | 111. | 75.2 | 42.2 | 229. | 139. | 94.5 | 1.1 | 0.4 | 2.0 | 0.8 | 0.9 | 0.3 |
| NO _x - E.I. | 3.3 | 8.1 | 2.4 | 3.2 | 5.2 | 1.2 | 1.9 | 2.8 | 6.2 | 9.4 | 6.3 | 10.0 | 6.4 | 7.2 |
| SMOKE NO. | 0.8 | 0.8 | ---- | 0.6 | ---- | ---- | ---- | 1.2 | ---- | ---- | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 98.1 | 99.7 | 86.6 | 90.3 | 93.8 | 74.1 | 83.4 | 88.0 | 99.3 | 99.5 | 99.2 | 99.4 | 99.4 | 99.6 |
| PATTERN FACTOR | 0.64 | 0.41 | 1.20 | 1.07 | 0.73 | 1.05 | 0.71 | 0.63 | 0.36 | 0.66 | 0.56 | 0.53 | 0.33 | 0.34 |
| CO - EPAP CONTRIBUTION | 7.35 | 1.14 | 9.10 | 8.38 | 7.61 | 11.6 | 10.7 | 10.1 | 3.93 | 2.83 | 1.56 | 1.20 | 1.33 | 0.88 |
| THC - EPAP CONTRIBUTION | 0.83 | 0.04 | 10.1 | 6.86 | 2.85 | 20.9 | 12.7 | 8.62 | 0.16 | 0.06 | 0.11 | 0.05 | 0.05 | 0.02 |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | | |
|--|------|-------|------|------|------|------|------|------|------|------|------|------|------|------|
| CO - E.I. | 53.8 | 1.3 | 83.4 | 76.1 | 67.9 | 109. | 99.6 | 93.7 | 10.9 | 6.4 | 11.0 | 7.1 | 3.9 | 1.8 |
| THC - E.I. | 6.1 | 0.2 | 45.1 | 30.9 | 17.1 | 93.6 | 56.9 | 38.9 | 0.2 | 0.1 | 0.3 | 0.1 | 0.1 | 0.05 |
| NO _x - E.I. | 3.1 | 9.2* | 3.8 | 4.8 | 8.0 | 2.0 | 2.7 | 3.7 | 14.2 | 21.4 | 14.3 | 22.8 | 16.1 | 18.4 |
| COMBUSTION EFFICIENCY % | 98.1 | 100 | 93.5 | 95.1 | 96.7 | 88.1 | 92.0 | 93.9 | 99.7 | 99.8 | 99.7 | 99.8 | 99.8 | 99.9 |
| CO - EPAP CONTRIBUTION | 7.35 | 0.11 | 7.61 | 6.94 | 6.19 | 9.92 | 9.08 | 8.55 | 1.62 | 0.96 | 1.63 | 1.05 | 0.48 | 0.22 |
| THC - EPAP CONTRIBUTION | 0.83 | 0.01 | 4.11 | 2.81 | 1.56 | 8.54 | 5.19 | 3.55 | 0.03 | 0.01 | 0.05 | 0.02 | 0.01 | -0- |
| NO _x - EPAP CONTRIBUTION | 0.42 | 0.84* | 0.35 | 0.44 | 0.73 | 0.18 | 0.25 | 0.34 | 2.11 | 3.18 | 2.13 | 3.39 | 0.92 | 1.05 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

@ -- ALTERNATE MAIN INJECTORS FUELED

APPENDIX E-2-b

GE RADIAL/AXIAL CONFIGURATION R/A-2 cont.

1. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | CRUISE | | | | | | |
|-------------------------------|--------------------|---------------|--------------------|--------------------|--------------------|---|---|---|
| READING NUMBER | TO-3 | CR-1 | CR-2 | CR-3 | CR-4 | CR-5 | CR-6 | CR-7 |
| FUELING MODE | PILOT & MAIN | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT [@] & $\frac{1}{2}$ MAIN | PILOT [@] & $\frac{1}{2}$ MAIN | PILOT [@] & $\frac{1}{2}$ MAIN |
| INLET PRESSURE ATM. | 4.59 | 4.78 | 4.78 | 4.73 | 4.74 | 4.79 | 4.78 | 4.77 |
| FUEL-AIR RATIO-PILOT | .0069 | .0210 | .0052 | .0063 | .0078 | .0048 | .0058 | .0074 |
| FUEL-AIR RATIO-TOTAL | .0230 | .0210 | .0223 | .0221 | .0223 | .0206 | .0207 | .0211 |
| CO - E.I. | 10.8 | 6.7 | 40.4 | 34.4 | 29.2 | 41.2 | 29.8 | 32.3 |
| THC - E.I. | 0.2 | 0.3 | 5.9 | 3.1 | 1.7 | 5.9 | 3.9 | 2.7 |
| NO _x - E.I. | 9.8 | 7.5 | 4.9 | 5.7 | 8.0 | 4.6 | 5.3 | 6.7 |
| SMOKE NO. | ---- | 5.3 | ---- | ---- | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.7 | 99.8 | 98.5 | 98.9 | 99.2 | 98.5 | 98.8 | 99.0 |
| PATTERN FACTOR | 0.33 | 0.32 | 0.32 | 0.32 | 0.31 | 0.62 | 0.31 | 0.32 |
| CO - EPAP CONTRIBUTION | 0.62 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | 0.01 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | |
|---|------|------|------|------|------|------|------|------|
| CO - E.I. | 1.8 | 1.2 | 29.2 | 23.7 | 19.2 | 29.8 | 19.8 | 22.0 |
| THC - E.I. | 0.03 | 0.1 | 2.5 | 1.3 | 0.7 | 2.5 | 1.6 | 1.1 |
| NO _x - E.I. | 24.9 | 10.8 | 7.2 | 8.2 | 11.7 | 6.8 | 7.8 | 9.8 |
| COMBUSTION EFFICIENCY % | 100 | 100 | 99.1 | 99.3 | 99.5 | 99.1 | 99.4 | 99.4 |
| CO - EPAP CONTRIBUTION | 0.10 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | -0- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| NO _x - EPAP CONTRIBUTION. | 1.42 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

@ -- ALTERNATE MAIN INJECTORS FUELED

APPENDIX E-3-a -

GE RADIAL/AXIAL COMBUSTOR DATA, CONFIGURATION R/A-3

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | | | APPROACH | | CLIMBOUT | | | | | | | |
|-------------------------------|---------------|------------------|--------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------------------|-------------------------------------|
| READING NUMBER | ID-1 | ID-2 6% BLEED | ID-3 1.2% BLEED | APP-1 | APP-2 | CL-1 | CL-2 | CL-3 | CL-4 | CL-5 | CL-6 | CL-7 | CL-8 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT [@] & 1/2 MAIN | PILOT [@] & 1/2 MAIN |
| INLET PRESSURE ATM. | 2.89 | 2.90 | 2.85 | 3.39 | 6.80 | 4.74 | 9.53 | 9.53 | 4.72 | 9.53 | 4.68 | 4.74 | 4.76 |
| FUEL-AIR RATIO-PILOT | .0110 | .0137 | .0159 | .0140 | .0140 | .0039 | .0039 | .0048 | .0048 | .0068 | .0070 | .0039 | .0068 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0137 | .0159 | .0140 | .0140 | .0212 | .0212 | .0211 | .0213 | .0210 | .0215 | .0211 | .0209 |
| CO - E.I. | 58.3 | 47.9 | 46.8 | 16.2 | 7.1 | 73.0 | 65.8 | 46.6 | 56.4 | 29.9 | 33.1 | 51.6 | 30.4 |
| THC - E.I. | 14.4 | 3.4 | 2.7 | 0.2 | 0.3 | 60.7 | 27.3 | 7.6 | 19.9 | 1.7 | 3.7 | 14.3 | 2.4 |
| NO _x - E.I. | 3.2 | 3.2 | 3.1 | 6.2 | 7.6 | 3.8 | 5.6 | 7.8 | 5.3 | 12.6 | 9.0 | 6.5 | 11.2 |
| SMOKE NO. | 0.8 | ---- | ---- | 2.2 | 1.6 | ---- | ---- | ---- | ---- | 0.9 | 2.6 | ---- | 2.3 |
| COMBUSTION EFFICIENCY % | 97.2 | 98.5 | 98.6 | 99.6 | 99.8 | 92.2 | 95.7 | 98.2 | 96.7 | 99.1 | 98.9 | 97.4 | 99.1 |
| PATTERN FACTOR | 0.68 | 0.51 | 0.57 | 0.51 | 0.70 | 0.41 | 0.38 | 0.33 | 0.32 | 0.28 | 0.27 | 0.43 | 0.57 |
| CO - EPAP CONTRIBUTION | 7.96 | 6.54 | 6.39 | 1.48 | 0.65 | 10.9 | 9.79 | 6.93 | 8.39 | 4.45 | 4.92 | 7.67 | 4.52 |
| THC - EPAP CONTRIBUTION | 1.97 | 0.46 | 0.37 | 0.02 | 0.03 | 9.03 | 4.06 | 1.13 | 2.96 | 0.25 | 0.55 | 2.13 | 0.36 |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | | |
|--|------|------|------|-------|-------|------|------|------|------|------|------|------|------|
| CO - E.I. | 58.8 | 47.6 | 45.7 | 1.1 | 0.9 | 47.8 | 50.3 | 33.1 | 33.9 | 18.8 | 15.8 | 30.0 | 13.9 |
| THC - E.I. | 14.3 | 3.4 | 2.7 | 0.1 | 0.2 | 11.1 | 10.0 | 2.8 | 3.6 | 0.6 | 0.7 | 2.6 | 0.4 |
| NO _x - E.I. | 3.0 | 3.1 | 3.0 | 7.4* | 7.6* | 8.4 | 8.6 | 12.0 | 11.7 | 19.4 | 20.3 | 14.9 | 25.2 |
| COMBUSTION EFFICIENCY % | 97.2 | 98.5 | 98.7 | 100 | 100 | 97.8 | 97.8 | 98.9 | 98.9 | 99.5 | 99.6 | 99.0 | 99.6 |
| CO - EPAP CONTRIBUTION | 7.89 | 6.50 | 6.24 | 0.10 | 0.08 | 7.11 | 7.48 | 4.92 | 5.04 | 2.80 | 2.35 | 4.46 | 2.07 |
| THC - EPAP CONTRIBUTION | 1.95 | 0.47 | 0.37 | 0.01 | 0.02 | 1.65 | 1.49 | 0.42 | 0.54 | 0.09 | 0.10 | 0.39 | 1.67 |
| NO _x - EPAP CONTRIBUTION | 0.41 | 0.42 | 0.41 | 0.67* | 0.70* | 1.25 | 1.28 | 1.78 | 1.74 | 2.89 | 3.02 | 2.22 | 3.75 |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

@ -- ALTERNATE MAIN INJECTORS FUELED

APPENDIX E-3-b .

GE RADIAL/AXIAL CONFIGURATION R/A-3 cont.

1. TEST RIG DATA

| ENGINE CONDITION | TAKE-OFF | | | | | | NO CRUISE DATA OBTAINED |
|-------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|
| READING NUMBER | TO-1 | TO-2 | TO-3 | TO-4 | TO-5 | TO-6 | |
| FUELING MODE | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 4.74 | 9.53 | 4.74 | 9.53 | 4.74 | 9.53 | |
| FUEL-AIR RATIO-PILOT | .0039 | .0040 | .0050 | .0050 | .0069 | .0070 | |
| FUEL-AIR RATIO-TOTAL | .0228 | .0231 | .0231 | .0232 | .0230 | .0232 | |
| CO - E.I. | 13.7 | 27.2 | 28.1 | 14.9 | 16.0 | 8.1 | |
| THC - E.I. | 12.1 | 4.6 | 2.4 | 1.0 | 0.5 | 0.5 | |
| NO _x - E.I. | 5.8 | 7.2 | 7.5 | 8.9 | 10.3 | 14.3 | |
| SMOKE NO. | ---- | ---- | ---- | ---- | 2.0 | 0.5 | |
| COMBUSTION EFFICIENCY % | 97.8 | 98.9 | 99.1 | 99.6 | 99.6 | 99.8 | |
| PATTERN FACTOR | 0.40 | 0.30 | 0.32 | 0.30 | 0.28 | 0.27 | |
| CO - EPAP CONTRIBUTION | 2.50 | 1.55 | 1.60 | 0.85 | 0.91 | 0.46 | |
| THC - EPAP CONTRIBUTION | 0.69 | 0.26 | 0.14 | 0.06 | 0.03 | 0.03 | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | |
|---|------|------|------|------|-------|------|--|
| CO - E.I. | 22.7 | 15.4 | 11.5 | 6.3 | 4.3 | 2.2 | |
| THC - E.I. | 1.9 | 1.5 | 0.4 | 0.3 | 0.1 | 0.2 | |
| NO _x - E.I. | 13.4 | 11.7 | 17.0 | 14.2 | 23.9 | 22.9 | |
| COMBUSTION EFFICIENCY % | 99.3 | 99.5 | 99.7 | 99.8 | 99.9 | 99.9 | |
| CO - EPAP CONTRIBUTION | 1.30 | 0.88 | 0.66 | 0.36 | 0.24 | 0.12 | |
| THC - EPAP CONTRIBUTION | 0.11 | 0.08 | 0.02 | 0.02 | 0.005 | 0.01 | |
| NO _x - EPAP CONTRIBUTION. | 0.77 | 0.67 | 0.97 | 0.81 | 1.36 | 1.31 | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

APPENDIX E-4

GE RADIAL/AXIAL COMBUSTOR DATA, CONFIGURATION R/A-4

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | CLIMBOUT | | | | TAKE-OFF | | | CRUISE | | |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | ID-1 | APP-1 | CL-1 | CL-2 | CL-3 | CL-4 | TO-1 | TO-2 | TO-3 | CR-1 | CR-2 | CR-3 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.89 | 3.42 | 4.76 | 4.76 | 4.77 | 4.75 | 4.76 | 4.77 | 4.76 | 4.75 | 4.78 | 4.78 |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0038 | .0048 | .0068 | .0097 | .0040 | .0050 | .0069 | .0049 | .0069 | .0077 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0217 | .0214 | .0214 | .0215 | .0230 | .0230 | .0229 | .0207 | .0208 | .0207 |
| CO - E.I. | 13.3 | 17.8 | 84.8 | 73.5 | 56.7 | 51.1 | 58.1 | 37.7 | 23.5 | 79.6 | 87.8 | 79.6 |
| THC - E.I. | 1.4 | 0.9 | 83.5 | 30.4 | 8.3 | 5.4 | 29.8 | 6.5 | 1.6 | 86.9 | 31.4 | 16.6 |
| NO _x - E.I. | 3.3 | 4.5 | 2.3 | 3.5 | 7.1 | 10.1 | 3.4 | 5.1 | 9.0 | 2.8 | 5.5 | 7.1 |
| SMOKE NO. | 0 | 1. | --- | 1. | --- | --- | --- | 0 | --- | --- | --- | --- |
| COMBUSTION EFFICIENCY % | 98.8 | 99.5 | 89.7 | 95.2 | 97.8 | 98.3 | 95.7 | 98.5 | 99.3 | 89.0 | 94.8 | 96.5 |
| PATTERN FACTOR | 0.60 | 0.67 | 0.36 | 0.34 | 0.25 | 0.31 | 0.32 | 0.30 | 0.27 | 0.36 | 0.27 | 0.25 |
| CO - EPAP CONTRIBUTION | 5.91 | 1.62 | 12.6 | 10.9 | 8.43 | 7.60 | 3.32 | 2.15 | 1.34 | --- | --- | --- |
| THC - EPAP CONTRIBUTION | 0.20 | 0.08 | 12.4 | 4.52 | 1.23 | 0.80 | 1.70 | 0.37 | 0.09 | --- | --- | --- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | | |
|--|------|-------|------|------|------|------|------|------|------|------|------|------|
| CO - E.I. | 12.8 | 1.5 | 54.4 | 48.3 | 34.3 | 29.7 | 84.0 | 18.3 | 8.6 | 64.8 | 72.5 | 64.8 |
| THC - E.I. | 1.4 | 0.3 | 15.4 | 5.6 | 1.5 | 1.0 | 4.8 | 1.0 | 0.3 | 36.1 | 13.1 | 6.9 |
| NO _x - E.I. | 3.1 | 5.6* | 5.2 | 8.1 | 15.6 | 22.6 | 8.5 | 12.4 | 21.9 | 4.4 | 8.4 | 10.2 |
| COMBUSTION EFFICIENCY % | 98.9 | 99.9 | 97.2 | 98.3 | 99.0 | 99.2 | 98.7 | 99.5 | 99.8 | 94.9 | 97.0 | 97.8 |
| CO - EPAP CONTRIBUTION | 5.84 | 0.14 | 8.09 | 7.18 | 5.10 | 4.42 | 1.94 | 1.05 | 0.49 | --- | --- | --- |
| THC - EPAP CONTRIBUTION | 0.20 | 0.02 | 2.28 | 0.83 | 0.23 | 0.15 | 0.27 | 0.06 | 0.01 | --- | --- | --- |
| NO _x - EPAP CONTRIBUTION | 0.43 | 0.51* | 0.77 | 1.20 | 2.32 | 3.36 | 0.49 | 0.71 | 1.25 | --- | --- | --- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX E-5

GE RADIAL/AXIAL COMBUSTOR DATA, CONFIGURATION R/A-5

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | CLIMBOUT | | | TAKE-OFF | | CRUISE | | |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| READING NUMBER | ID-1 | APP-1 | CL-1 | CL-2 | CL-3 | TO-1 | TO-2 | CR-1 | CR-2 | CR-3 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.90 | 3.41 | 4.70 | 4.78 | 4.76 | 4.71 | 4.73 | 4.74 | 4.78 | 4.76 |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0040 | .0050 | .0068 | .0040 | .0050 | .0045 | .0069 | .0083 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0214 | .0214 | .0209 | .0227 | .0230 | .0207 | .0208 | .0208 |
| CO - E.I. | 41.0 | 15.6 | 78.3 | 53.3 | 41.0 | 44.3 | 36.7 | 88.0 | 60.3 | 53.0 |
| THC - E.I. | 2.0 | 0.8 | 83.7 | 17.1 | 4.2 | 3.3 | 4.4 | 72.4 | 10.3 | 5.2 |
| NO _x - E.I. | 3.4 | 7.0 | 2.1 | 3.0 | 5.4 | 7.9 | 10.0 | 2.2 | 4.4 | 5.7 |
| SMOKE NO. | 1. | ---- | ---- | 5. | ---- | ---- | ---- | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 98.8 | 99.6 | 89.8 | 97.0 | 98.6 | 98.6 | 98.7 | 90.7 | 97.6 | 98.2 |
| PATTERN FACTOR | 0.26 | 0.31 | 0.33 | 0.29 | 0.24 | 0.24 | 0.17 | 0.31 | 0.35 | 0.41 |
| CO - EPAP CONTRIBUTION | 5.60 | 1.42 | 11.7 | 7.93 | 6.10 | 2.53 | 2.10 | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | 0.27 | 0.08 | 12.5 | 2.54 | 0.62 | 0.19 | 0.25 | ---- | ---- | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | |
|--|------|-------|------|------|------|------|------|------|------|------|
| CO - E.I. | 40.7 | 0.2 | 52.3 | 31.5 | 21.8 | 23.1 | 17.5 | 72.6 | 47.0 | 40.3 |
| THC - E.I. | 2.0 | 0.2 | 15.2 | 3.2 | 0.8 | 0.5 | 0.7 | 30.0 | 4.3 | 2.2 |
| NO _x - E.I. | 3.4 | 7.9* | 4.6 | 6.3 | 11.2 | 18.4 | 22.9 | 3.2 | 6.2 | 8.0 |
| COMBUSTION EFFICIENCY % | 98.8 | 100 | 97.3 | 98.9 | 99.4 | 99.4 | 99.5 | 95.3 | 98.5 | 98.8 |
| CO - EPAP CONTRIBUTION | 5.56 | 1.42 | 7.78 | 4.69 | 3.24 | 1.32 | 1.00 | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | 0.27 | 0.02 | 2.26 | 0.48 | 0.12 | 0.03 | 0.04 | ---- | ---- | ---- |
| NO _x - EPAP CONTRIBUTION | 0.46 | 0.72* | 0.61 | 0.93 | 1.71 | 1.05 | 1.31 | ---- | ---- | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P^{0.2} NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX E-6

GE RADIAL/AXIAL COMBUSTOR DATA, CONFIGURATION R/A-6

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | | | CLIMBOUT | NO TAKE-OFF DATA | CRUISE | | |
|-------------------------------|---------------|---------------|--------------------|--------------------|--------------------|---------------------|--------------------|--------------------|--------------------|
| READING NUMBER | ID-1 | APP-1 | APP-2 | APP-3 | CL-1 | | CR-1 | CR-2 | CR-3 |
| FUELING MODE | PILOT ONLY | PILOT ONLY | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN |
| INLET PRESSURE ATM. | 2.96 | 3.48 | 3.50 | 3.60 | 4.77 | | 4.77 | 4.77 | 4.92 |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0048 | .0070 | .0071 | | .0050 | .0072 | .0079 |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0137 | .0139 | .0214 | | .0210 | .0213 | .0208 |
| CO - E.I. | 23.4 | 13.2 | 105. | 138. | 20.0 | | 73.4 | 39.2 | 38.7 |
| THC - E.I. | 0.5 | 0.1 | 375. | 203. | 3.0 | | 30.0 | 2.2 | 2.4 |
| NO _x - E.I. | 3.2 | 7.9 | 0.8 | 1.8 | 6.0 | | 3.5 | 5.5 | 5.9 |
| SMOKE NO. | ---- | 1. | ---- | ---- | ---- | | ---- | ---- | ---- |
| COMBUSTION EFFICIENCY % | 99.4 | 99.7 | 60.1 | 76.4 | 99.2 | | 95.3 | 98.9 | 98.9 |
| PATTERN FACTOR | 0.36 | 0.28 | 0.83 | 0.41 | 0.30 | | 0.23 | 0.24 | 0.35 |
| CO - EPAP CONTRIBUTION | 3.20 | 1.20 | 9.55 | 12.6 | 2.97 | | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | 0.06 | 0.01 | 34.2 | 18.6 | 0.45 | | ---- | ---- | ---- |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | |
|---|------|-------|------|------|------|--|------|------|------|
| CO - E.I. | 23.9 | 0.7 | 82.8 | 115. | 11.5 | | 59.1 | 28.0 | 27.9 |
| THC - E.I. | 0.5 | 0.03 | 112. | 62.6 | 0.6 | | 12.5 | 0.9 | 1.0 |
| NO _x - E.I. | 2.9 | 9.2* | 1.6 | 3.2 | 13.6 | | 5.1 | 7.8 | 8.3 |
| COMBUSTION EFFICIENCY % | 99.4 | 100 | 86.9 | 91.1 | 99.7 | | 97.4 | 99.3 | 99.2 |
| CO - EPAP CONTRIBUTION | 3.26 | 0.06 | 7.55 | 10.5 | 1.71 | | ---- | ---- | ---- |
| THC - EPAP CONTRIBUTION | 0.07 | -0- | 10.2 | 5.71 | 0.08 | | ---- | ---- | ---- |
| NO _x - EPAP CONTRIBUTION. | 0.39 | 0.84* | 0.15 | 0.29 | 2.02 | | ---- | ---- | ---- |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P_x^2 NO_x EXTRAPOLATION TO ENGINE PRESSURE

APPENDIX E-7

GE RADIAL/AXIAL COMBUSTOR DATA, CONFIGURATION R/A-7

1. TEST RIG DATA

| ENGINE CONDITION | IDLE | APPROACH | CLIMBOUT | | | TAKE-OFF | | | CRUISE | | |
|-------------------------------|-------|----------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--|
| READING NUMBER | ID-1 | APP-1 | CL-1 | CL-2 | CL-3 | TO-1 | TO-2 | TO-3 | CR-1 | CR-2 | |
| FUELING MODE | PILOT | PILOT | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | PILOT & MAIN | |
| INLET PRESSURE ATM. | 2.92 | 3.40 | 4.72 | 4.72 | 4.74 | 4.76 | 9.53 | 4.74 | 4.74 | 4.74 | |
| FUEL-AIR RATIO-PILOT | .0110 | .0140 | .0039 | .0050 | .0070 | .0048 | .0049 | .0058 | .0048 | .0078 | |
| FUEL-AIR RATIO-TOTAL | .0110 | .0140 | .0222 | .0218 | .0217 | .0233 | .0231 | .0235 | .0206 | .0209 | |
| CO - E.I. | 52.0 | 9.0 | 65.5 | 85.8 | 117.9 | 60.2 | 111.2 | 30.3 | 77.1 | 72.6 | |
| THC - E.I. | 8.6 | 0.2 | 187. | 98.4 | 11.9 | 33.3 | 19.0 | 4.7 | 161. | 30.7 | |
| NO _x - E.I. | 2.8 | 5.2 | 0.7 | 1.3 | 3.2 | 2.8 | 4.4 | 3.9 | 1.8 | 2.9 | |
| SMOKE NO. | ---- | 0.2 | 0.9 | 2.9 | 1.1 | 1.1 | 0.9 | 0.8 | ---- | ---- | |
| COMBUSTION EFFICIENCY % | 97.9 | 99.8 | 79.7 | 88.2 | 97.7 | 95.3 | 97.2 | 98.8 | 82.1 | 95.2 | |
| PATTERN FACTOR | 0.62 | 0.38 | 0.66 | 0.69 | 0.45 | 0.53 | 0.42 | 0.45 | 0.91 | 0.43 | |
| CO - EPAP CONTRIBUTION | 7.10 | 0.82 | 9.74 | 12.8 | 7.12 | 3.44 | 2.35 | 1.73 | ---- | ---- | |
| THC - EPAP CONTRIBUTION | 1.17 | 0.02 | 27.8 | 14.6 | 1.77 | 1.90 | 1.08 | 0.27 | ---- | ---- | |

2. DATA CORRECTED TO ENGINE PRESSURES:

| | | | | | | | | | | | |
|---|------|-------|-------|------|------|------|------|------|------|------|--|
| CO - E.I. | 52.0 | 0.2 | 111.4 | 58.7 | 27.1 | 35.7 | 27.0 | 12.9 | 62.4 | 58.2 | |
| THC - E.I. | 8.6 | 0.1 | 31.1 | 17.9 | 2.2 | 5.3 | 6.1 | 0.8 | 66.7 | 12.7 | |
| NO _x - E.I. | 2.6 | 7.0* | 1.6 | 3.1 | 7.1 | 6.9 | 7.6 | 9.1 | 3.1 | 4.4 | |
| COMBUSTION EFFICIENCY % | 97.9 | 100 | 95.6 | 96.8 | 99.2 | 98.6 | 99.6 | 98.8 | 91.9 | 97.4 | |
| CO - EPAP CONTRIBUTION | 7.10 | 0.01 | 6.16 | 8.73 | 4.03 | 2.04 | 1.54 | 0.74 | ---- | ---- | |
| THC - EPAP CONTRIBUTION | 1.17 | 0.005 | 5.07 | 2.66 | 0.33 | 0.30 | 0.35 | 0.04 | ---- | ---- | |
| NO _x - EPAP CONTRIBUTION. | 0.36 | 0.64* | 0.24 | 0.46 | 1.06 | 0.39 | 0.43 | 0.54 | ---- | ---- | |

COMBUSTOR INLET TEMPERATURE AND REFERENCE VELOCITY AT NOMINAL ENGINE CONDITIONS.

* -- P² NO_x EXTRAPOLATION TO ENGINE PRESSURE

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⊖ Testing complete.

Closed symbols indicate completed items.

Open symbols indicate planned completion date.

TABLE II. - POLLUTION GOALS

| POLLUTANT | ENGINE MODE | PROGRAM GOAL | 1979 EPA STANDARD | JT9D-7 ENGINE EMISSIONS DATA P.R. 22:1 | CF6-50 ENGINE EMISSIONS DATA P.R. 30:1 |
|--|-------------|--------------|-------------------|---|---|
| OXIDES OF NITROGEN AS NO ₂ - E.I. | TAKE-OFF | 10 | 13 | 32 | 36 |
| CARBON MONOXIDE E.I. | IDLE | 20 | 22.5 | 77 | 73 |
| TOTAL UNBURNED HYDROCARBONS E.I. | IDLE | 4 | 4.5 | 30 | 30 |
| SMOKE - SAE | TAKE-OFF | 15 | 19 | 10 | 13 |

TABLE III. - EPA PARAMETER VALUES

| ENGINE | CARBON MONOXIDE | TOTAL UNBURNED HYDROCARBONS | OXIDES OF NITROGEN |
|---|-----------------|-----------------------------|--------------------|
| REQUIRED EPA VALUES T-2 ENGINE CLASS | 4.3 | 0.8 | 3.0 |
| CF6-50 ENGINE P.R. - 30:1 | | | |
| CURRENT VALUES | 10.8 | 4.3 | 7.7 |
| % CURRENT VALUES EXCEED REQUIREMENTS | 151. | 438. | 157. |
| JT9D-7 ENGINE P.R. - 22:1 | | | |
| CURRENT VALUES | 14.29 | 5.34 | 4.90 |
| % CURRENT VALUES EXCEED REQUIREMENTS | 232. | 568. | 63. |

TABLE IV. - PERFORMANCE GOALS

| PARAMETER | ENGINE MODE | PROGRAM GOAL |
|-----------------------|-----------------------------------|--------------|
| COMBUSTION EFFICIENCY | ALL MODES | 99%+ |
| PRESSURE LOSS | CRUISE | 6% |
| PATTERN FACTOR | TAKE-OFF, CRUISE | 0.25 |
| ALTITUDE RELIGHT | WINDMILLING | |
| DURABILITY | ADEQUATE AT ALL ENGINE CONDITIONS | |

TABLE V. - POLLUTION CONSIDERATIONS

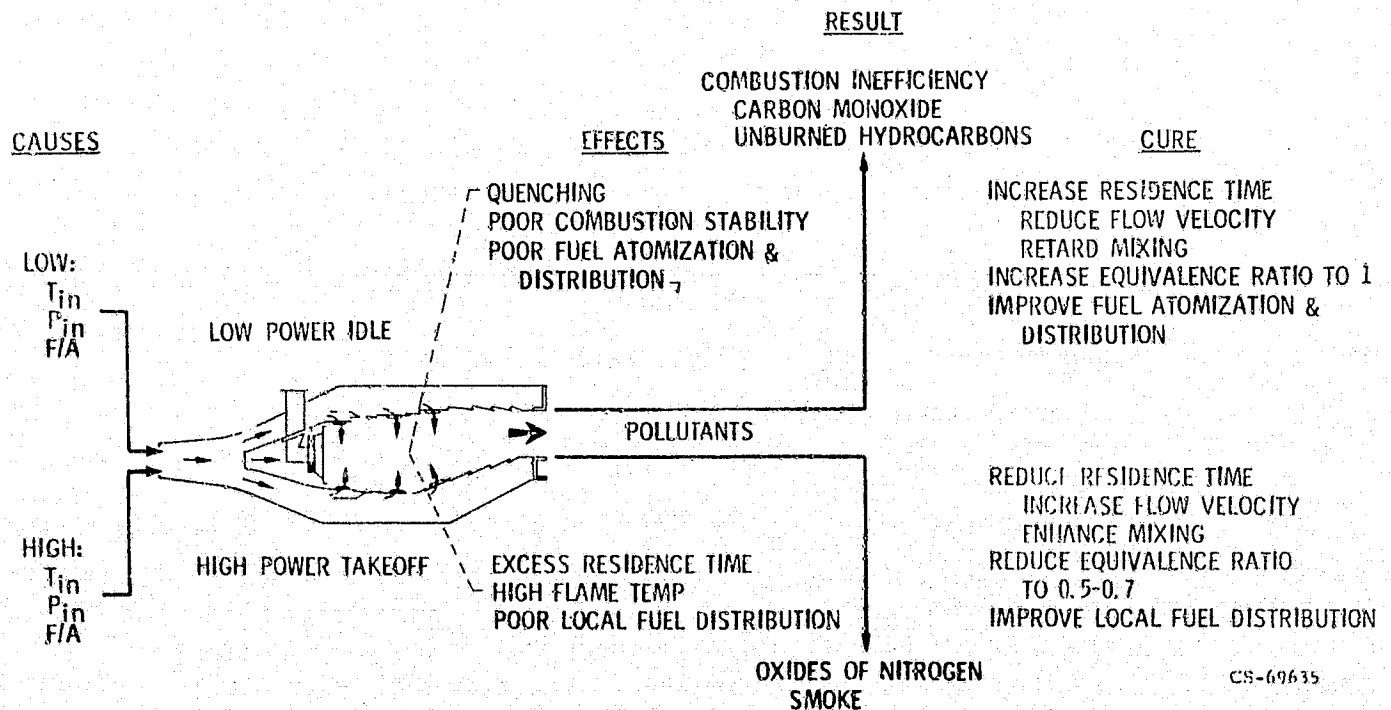


TABLE VI. - KEY SPECIFICATIONS OF THE JT9D-7 ENGINE

| | |
|--|------------------------|
| Weight (kg) | 3982.5 |
| Length (m) | 3.912 |
| Maximum diameter, cold (m) | 3.427 |
| Pressure ratio | 21.7 |
| Airflow rate (kg/s) | 691 |
| Maximum sea-level static thrust (kN) | 197 |
| Cruise performance | |
| Mach number | 0.85 |
| Altitude (m) | 10 668 |
| Thrust (kN) | 44.6 |
| Specific fuel consumption (kg/Ns). | 1.979×10^{-5} |

TABLE VII. - KEY OPERATING PARAMETERS OF THE JT9D-7

REFERENCE COMBUSTOR

| | |
|---|-----------------|
| Compressor exit axial Mach number | 0.258 |
| Compressor discharge temperature (K) | 768.9 |
| Combustor temperature rise (K) | 763.9 |
| Combustor section pressure loss (%) | 6.0 |
| Combustor exit temperature pattern factor | 0.42 ± 0.03 |
| Average combustor exit temperature (K) | 1532.8 |

NOTE: Data for standard day sea-level static take-off conditions.

TABLE VIII. - KEY SPECIFICATIONS OF THE CF6-50 ENGINE

| | |
|--------------------------------------|----------|
| Weight (kg) | 3780 |
| Length-cold (m) | 4.82 |
| Maximum diameter, cold (m) | 2.72 |
| Fan/comp. stages | 1-(3)/14 |
| HPT/LPT stages | 2/4 |
| Thrust/weight | 5.95 |
| Pressure ratio | 30:1 |
| Airflow (kg/s) | 660 |
| Maximum SLS thrust (kN) | 218 |
| Specific fuel consumption | 0.389 |
| Cruise performance | |
| Mach number | 0.85 |
| Altitude (m) | 10 500 |
| Thrust (kN) | 48 |
| Specific fuel consumption | 0.654 |

TABLE IX. - CF6-50 COMBUSTOR KEY DESIGN PARAMETERS

| | |
|---|----------------------|
| Combustor airflow (kg/s) | 103.42 |
| Compressor exit Mach number | 0.27 |
| Overall system length (m) | 0.7595 |
| Burning length (m) | 0.348 |
| Dome height (m) | 0.1143 |
| Reference velocity (m/s) | 25.9 |
| Space rate (l/hr-m ³ -atm) | 2.2×10 ¹¹ |
| Pressure loss-total (%) | 4.3 |
| Number of fuel nozzles | 30 |
| Fuel nozzle spacing (cm) | 6.91 |
| Burning length/fuel nozzle spacing | 5.0 |
| Fuel nozzle spacing/dome height | 0.60 |
| Design flow splits | |
| Outer-center-inner (% of combustor airflow) | 33-32-35 |
| Liner cooling flow (% of combustor airflow) | 30 |
| Exit temperature pattern factor | 0.26 |
| Exit temperature profile factor | 1.09 |
| Combustion efficiency (%) | 99.9 |

NOTE: Data for standard day sea-level static take-off conditions.

TABLE X. - TEST RIG CONDITIONS, SIMULATION OF JT9D-7 ENGINE-COMBUSTOR CONDITIONS, PRATT & WHITNEY

| Engine operating condition | Inlet pressure, atm | Inlet temperature, K | Fuel-air ratio | Reference velocity, m/sec | | Combustor exit temperature, K | Comments |
|----------------------------|---------------------|----------------------|----------------|---------------------------|--------|-------------------------------|-----------------------------|
| | | | | Vorbix | Hybrid | | |
| Standard day idle bled | 2.93 | 427 | 0.0126 | 19.2 | 33.2 | 886 | True engine conditions |
| Standard day idle unbled | 3.95 | 464 | 0.0100 | 21.0 | 36.6 | 850 | True engine conditions |
| Standard day approach | 6.80 | 586 | 0.0130 | 23.2 | 40.5 | 1006 | Engine pressure = 8.50 atm |
| Standard day climbout | 6.80 | 735 | 0.0194 | 25.6 | 45.1 | 1396 | Engine pressure = 18.50 atm |
| Standard day take-off | 6.80 | 767 | 0.0215 | 26.2 | 45.4 | 1486 | Engine pressure = 21.10 atm |
| CTOL cruise | 6.80 | 704 | 0.0205 | 24.7 | 43.6 | 1413 | Engine pressure = 9.31 atm |

TABLE XI. - TEST RIG CONDITIONS, SIMULATION OF CF6-50 ENGINE-COMBUSTOR
CONDITIONS, GENERAL ELECTRIC

| Engine operating condition | Inlet pressure, atm | Inlet temperature, K | Fuel-air ratio | Reference velocity, m/sec | Combustor exit temperature, K | Comments |
|--------------------------------|---------------------|----------------------|----------------|---------------------------|-------------------------------|----------------------------|
| Standard day idle | 2.92 | 429 | 0.0110 | 18.3 | 865 | True engine conditions |
| Standard day approach | 6.8 | 630 | 0.0140 | 23.2 | 1136 | Engine pressure = 11.7 atm |
| Standard day climbout | 9.5 | 786 | 0.0214 | 25.3 | 1503 | Engine pressure = 25.9 atm |
| Standard day take-off | 9.5 | 820 | 0.0231 | 25.6 | 1586 | Engine pressure = 29.8 atm |
| CTOL cruise 0.85 Mach ~35 K | 9.5 | 733 | 0.0210 | 24.4 | 1449 | Engine pressure = 11.4 atm |

TABLE XII. - SUMMARY OF PRESSURE EXPONENTS, ECCPII TESTS

| Emission | Operating condition | Pressure exponent used, n | Data statistical analysis | | | |
|-----------------|---------------------|---|---------------------------|-----------|--|-----------------------------|
| | | | N | \bar{n} | σ_n | $\frac{2\sigma_n}{\bar{n}}$ |
| NO _x | Approach | | | | | |
| | Pilot only | 0.2 | ¹ 17 | 0.241 | 0.104 | 0.862 |
| | Two stage | .5 | 12 | .456 | .102 | .450 |
| | Climbout | .5 | 3 | .507 | .085 | .336 |
| | Take-off | .5 | 23 | .489 | .115 | .469 |
| HC | All | 1.0 | ² 38 | 1.038 | 1.364 | 2.628 |
| CO | Pilot only | $0.6 \left(\frac{100}{EI_{CO}} \right)^{0.7} \leq 2.0$ | ³ 4 | 0.500 | $\left(\frac{100}{EI_{CO}} \right)^{0.7}$ | ≤ 2.0 |
| | Two stage | $0.2 \left(\frac{100}{EI_{CO}} \right)^{0.7} \leq 2.0$ | 40 | 0.191 | $\left(\frac{100}{EI_{CO}} \right)^{0.7}$ | ≤ 2.0 |

¹0.008 ≤ f ≤ 0.014.²EI_{CH,1} ≥ 0.2 g/kg.³f = 0.014.

N = number of data points.

$$\bar{n} = \frac{\sum n_i}{N}$$

$$\sigma_n = \sqrt{\frac{\sum n_i^2 - N\bar{n}^2}{N - 1}}$$

NOTE: Pressure range investigated, 4.8 to 9.6 atmospheres.

TABLE XIII. - CF6-50 ENGINE STATUS CYCLE PARAMETERS

| Cycle condition | Idle unbled | Approach | Climbout | Take-off |
|--------------------------------|-------------|----------|----------|----------|
| Ambient temperature, K | 288 | 288 | 288 | 288 |
| Ambient pressure, atm | 1.0 | 1.0 | 1.0 | 1.0 |
| F_n , kN | 7.53 | 60.59 | 188.66 | 221.95 |
| % F_n | 3.39 | 30.0 | 85.0 | 100.0 |
| N_g , rpm | 6412 | 8620 | 9890 | 10150 |
| Combustor inlet pressure, atm | 2.92 | 11.7 | 25.9 | 29.8 |
| Combustor inlet temperature, K | 429 | 630 | 786 | 820 |
| Fuel flow, ideal, kg/hr | 547 | 2395 | 7104 | 8573 |
| Airflow total, kg/s | 16.37 | 56.7 | 109.3 | 122.0 |
| Airflow combustor, kg/s | 13.81 | 47.6 | 92.1 | 103.0 |
| Reference velocity, m/sec | 18.3 | 23.2 | 25.3 | 25.6 |
| Fuel-air ratio, ideal | 0.0110 | 0.0140 | 0.0214 | 0.0231 |
| Combustor exit temperature, K | 865 | 1136 | 1503 | 1586 |

NOTE: Fuel flows and fuel-air ratios assume combustion efficiency = 100%.

TABLE XIV. - EPAP COEFFICIENTS FOR ECCP II/CF6-50C

(Class T₂ Engine)

| Power Level | t Minutes | F _N lb _f | W _F ⁽²⁾ pph | $\left(\frac{t}{60}\right) \left(\frac{F_N}{1000}\right)$ Klb _f -hr. | $\left(\frac{t}{60}\right) \left(\frac{W_F}{1000}\right)$ Klb _m -hr. | C lb _m /lb _f -hr. | $\left(\frac{4.3}{C}\right)$ | $\left(\frac{0.8}{C}\right)$ | $\left(\frac{3.0}{C}\right)$ |
|---------------------|--------------|-----------------------------------|--------------------------------------|--|--|--|------------------------------|------------------------------|------------------------------|
| Idle ⁽¹⁾ | 26.0 | 1,692 | 1,219 | 0.7331 | 0.5282 | 0.1365 | 31.49 | 5.859 | 21.97 |
| Approach | 4.0 | 14,969 | 5,292 | 0.9979 | 0.3528 | 0.0912 | 47.15 | 8.771 | 32.89 |
| Climb | 2.2 | 42,412 | 15,692 | 1.5551 | 0.5753 | 0.1487 | 28.91 | 5.379 | 20.17 |
| Takeoff | 0.7 | 49,896 | 18,938 | 0.5821 | 0.2209 | 0.0571 | 75.30 | 14.010 | 52.53 |
| Σ | | | | 3.8682 | | | | | |

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$$EPAP_i = \sum_j [C_j (EI_{ij})] = (EPAP_i, \text{std}) \sum_j \left[\frac{EI_{ij}}{\left(\frac{EPAP_i, \text{std}}{C_j}\right)} \right]$$

$$(EPAP_{CO, \text{std}}) = 4.3, \quad (EPAP_{HC, \text{std}}) = 0.8, \quad (EPAP_{NO_x, \text{std}}) = 3.0 \text{ lb}_m/\text{Klb}_f\text{-hr.}$$

(1) Assumes no CDP bleed or thrust reverse.

(2) Assumes target levels of combustion efficiency (99.0% at idle, 99.8% elsewhere).

TABLE XV. - CF6-50 PRODUCTION ENGINE EMISSION INDEX
AND EPAP VALUES

| <u>ENGINE MODE</u> | <u>E.I. THC</u> | <u>E.I. CO</u> | <u>E.I. NO_x</u> |
|--------------------|-----------------|----------------|----------------------------|
| IDLE | 30 | 73 | 2.5 |
| APPROACH | 0.01 | 4.3 | 10.0 |
| CLIMBOUT | 0.01 | 0.3 | 29.5 |
| TAKE-OFF | 0.01 | 0.2 | 35.5 |
| EPAP | 4.3 | 10.8 | 7.7 |

TABLE XVI. - JT9D-7 ENGINE STATUS CYCLE PARAMETERS

| <u>PARAMETER</u> | <u>IDLE BLED</u> | <u>IDLE UNBLED</u> | <u>APPROACH</u> | <u>CLIMBOUT</u> | <u>TAKE-OFF</u> |
|--------------------------|----------------------|------------------------|-----------------|-----------------|-----------------|
| F _n , kN | ---- | 16.90 | 61.59 | 174.50 | 205.3 |
| Inlet air temperature, K | 428 | 464 | 586 | 735 | 767 |
| Fuel flow, kg/hr | 728 | 839 | 2109 | 5986 | 7324 |
| TSFC | --- | .4868 | .3359 | .3365 | .3499 |
| Inlet pressure, atm | 2.93 | 3.95 | 8.50 | 18.50 | 21.1 |
| Fuel air ratio * | | | | | |
| EPAP coefficient | .0126 | .0100 | .0130 | .0194 | .0215 |
| % of total | .1728 44.9 | .1763 44.9 | .0682 17.4 | .1065 27.1 | .0414 10.6 |

NOTE:

* -- Assumes combustion efficiency = 99 % at idle; 100 % at all other conditions.

-- Engine nominal by-pass ratio - 520; compressor ratio - 202

TABLE XVII. - CURRENT PRODUCTION JT9D-7 ENGINE EMISSION
LEVELS (dry basis)

| POLLUTANT | E.I. THC | E.I. CO | E.I. NO _x |
|--------------|----------|---------|----------------------|
| IDLE, UNBLED | 29.8 | 77.0 | 3.3 |
| APPROACH | 1.0 | 9.6 | 8.4 |
| CLIMBOUT | 0.1 | 0.5 | 22.9 |
| TAKE-OFF | 0.05 | 0.2 | 31.5 |
| EPAP | 5.34 | 14.29 | 4.9 |

TABLE XVIII- PHASE II VORBIT COMBUSTOR CONFIGURATIONS, ENGINE MODE CONTRIBUTIONS TO EPAP NUMBERS AND TOTAL EPAP NUMBERS.

| ENGINE OPERATING MODE: | | IDLE CONTRIBUTION | | | APPROACH CONTRIBUTION | | | CLIMBOUT CONTRIBUTION | | | TAKE-OFF CONTRIBUTION | | | TOTAL EPAP NUMBER | | |
|--|------------------------|----------------------|-------|-------|--------------------------|-------|-------|--------------------------|-------|-------|--------------------------|-------|-------|-------------------|-------|-------|
| | | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx |
| 1979-EPA STANDARDS | LOWEST COMBINED VALUES | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 4.3 | 0.8 | 3.0 |
| JT9D-7 ENGINE | LOWEST COMBINED VALUES | 13.58 | 5.25 | 0.58 | 0.65 | 0.07 | 0.57 | 0.05 | 0.01 | 2.44 | 0.01 | -0- | 1.30 | 14.29 | 5.34 | 4.9 |
| CONFIGURATION S-11 | LOWEST NOx VALUES | 6.19 | 0.14 | 0.65 | 1.57 | 0.11 | 0.35 | 1.56 | 0.06 | 1.27 | 0.85 | 0.03 | 0.60 | 10.17 | 0.34 | 2.87 |
| | LOWEST CO & THC VALUES | " " | " " | " " | 0.80 | 0.03 | 0.46 | " " | " " | " " | 0.04 | 0.003 | 0.62 | 8.59 | 0.23 | 3.00 |
| | LOWEST COMBINED VALUES | " " | " " | " " | " " | " " | " " | " " | " " | " " | 0.08 | -0- | 0.67 | 8.63 | 0.23 | 3.05 |
| CONFIGURATION S-12,13 | LOWEST NOx VALUES | 6.16 | 0.33 | 0.55 | 0.23 | 0.02 | 0.64 | 1.42 | 0.04 | 1.31 | 1.78 | 0.02 | 0.62 | 9.59 | 0.41 | 3.12 |
| | LOWEST CO & THC VALUES | " " | " " | " " | " " | " " | " " | " " | " " | " " | 0.41 | 0.01 | 0.65 | 8.22 | 0.40 | 3.15 |
| | LOWEST COMBINED VALUES | " " | " " | " " | " " | " " | " " | " " | " " | " " | " " | " " | " " | 8.22 | 0.40 | 3.15 |
| CONFIGURATION S-14,15 (same pilot as S-12,13) | LOWEST NOx VALUES | 6.16 | 0.33 | 0.55 | 0.23 | 0.02 | 0.64 | ----- | ----- | ----- | 2.24 | 0.05 | 0.55 | ----- | ----- | ----- |
| | LOWEST CO & THC VALUES | " " | " " | " " | " " | " " | " " | ----- | ----- | ----- | 0.26 | -0.04 | -1.18 | ----- | ----- | ----- |
| | LOWEST COMBINED VALUES | " " | " " | " " | " " | " " | " " | ----- | ----- | ----- | 0.27 | 0.01 | 0.89 | ----- | ----- | ----- |
| CONFIGURATION S-16 | LOWEST NOx VALUES | 10.58 | 0.17 | 0.51 | ----- | ----- | ----- | ----- | ----- | ----- | 0.61 | 0.01 | 0.72 | ----- | ----- | ----- |
| | LOWEST CO & THC VALUES | " " | " " | " " | ----- | ----- | ----- | ----- | ----- | ----- | 0.10 | -0- | 0.93 | ----- | ----- | ----- |
| | LOWEST COMBINED VALUES | " " | " " | " " | ----- | ----- | ----- | ----- | ----- | ----- | " " | " " | " " | ----- | ----- | ----- |
| CONFIGURATION S-17 | LOWEST NOx VALUES | 9.55 | 0.22 | 0.43 | 0.65 | 0.02 | 0.29 | 0.03 | 0.02 | 1.10 | 0.90 | 0.01 | 0.47 | 11.13 | 0.27 | 2.29 |
| | LOWEST CO & THC VALUES | " " | " " | " " | " " | " " | " " | " " | " " | " " | -0- | " " | 0.48 | 10.23 | 0.27 | 2.30 |
| | LOWEST COMBINED VALUES | " " | " " | " " | " " | " " | " " | " " | " " | " " | " " | " " | " " | 10.23 | 0.27 | 2.30 |
| CONFIGURATION S-18 | LOWEST NOx VALUES | 12.02 | 0.21 | 0.48 | 4.32 | 2.28 | 0.25 | 1.54 | 0.04 | 1.54 | 0.90 | 0.01 | 0.84 | 18.78 | 2.54 | 3.11 |
| | LOWEST CO & THC VALUES | " " | " " | " " | 1.15 | 0.02 | 0.48 | " " | " " | " " | " " | -0- | 0.99 | 14.80 | 0.27 | 3.49 |
| | LOWEST COMBINED VALUES | " " | " " | " " | 1.13 | 0.08 | 0.41 | " " | " " | " " | " " | " " | " " | 14.78 | 0.33 | 3.42 |
| CONFIGURATION S-19 | LOWEST COMBINED VALUES | 10.94 | 0.04 | 0.46 | ----- | ----- | ----- | ----- | ----- | ----- | 0.15 | 0.84 | ----- | ----- | ----- | ----- |
| CONFIGURATION S-20 | LOWEST NOx VALUES | 7.97 | 1.10 | 0.51 | 1.54 | 0.26 | 0.34 | 1.35 | 0.03 | 1.22 | 1.94 | 0.17 | 0.54 | 12.80 | 1.56 | 2.61 |
| | LOWEST CO & THC VALUES | 4.66 | 0.62 | 0.69 | 0.54 | 0.02 | 0.61 | 0.23 | -0- | 1.59 | 0.44 | 0.003 | 0.57 | 5.87 | 0.64 | 3.46 |
| | LOWEST COMBINED VALUES | " " | " " | " " | 0.66 | 0.01 | 0.59 | " " | " " | " " | 0.70 | 0.005 | 0.61 | 6.25 | 0.60 | 3.48 |
| CONFIGURATION S-21 | LOWEST NOx VALUES | 7.40 | 0.55 | 0.48 | 3.67 | 1.62 | 0.29 | ----- | ----- | ----- | 3.29 | 0.35 | 0.48 | ----- | ----- | ----- |
| | LOWEST CO & THC VALUES | 4.76 | 0.29 | 0.57 | 1.39 | 0.14 | 0.45 | ----- | ----- | ----- | 0.19 | 0.01 | 0.89 | ----- | ----- | ----- |
| | LOWEST COMBINED VALUES | " " | " " | " " | " " | " " | " " | ----- | ----- | ----- | 0.26 | 0.01 | 0.83 | ----- | ----- | ----- |

TABLE XIX. - PRATT & WHITNEY VORBITX COMBUSTOR, BEST POLLUTION

PERFORMANCE RESULTS

| Combustor configurations | Engine mode | CO | | THC | | NO _x | | Combustion efficiency, percent |
|--------------------------|--------------------|-------|-------------------|------|-------------------|-----------------|-------------------|--------------------------------|
| | | EI | EPAP contribution | EI | EPAP contribution | EI | EPAP contribution | |
| S-11 | Idle bled | 36 | 6.19 | 0.82 | 0.14 | 3.78 | 0.65 | 99.1 |
| | Approach | 11.8 | .80 | .47 | .03 | 6.74 | .46 | 99.7 |
| | Climbout | 14.68 | 1.56 | .55 | .06 | 11.88 | 1.27 | 99.6 |
| | Take-off | 1.99 | .08 | 0 | 0 | 16.18 | .67 | 100 |
| | Σ EPAP | | 8.63 | | .23 | | 3.05 | |
| | Cruise | 28.4 | | 40.9 | | 6.22 | | 98.4 |
| S-20 | Idle bled | 46.3 | 7.97 | 6.41 | 1.10 | 2.98 | 0.51 | 98.3 |
| | Idle unbled | 26.4 | 4.66 | 3.52 | .62 | 3.89 | .69 | 99.0 |
| | Approach | 9.7 | .66 | .16 | .01 | 8.62 | .59 | 99.8 |
| | Climbout | 2.1 | .23 | 0 | 0 | 15.0 | 1.59 | 100 |
| | Take-off | 17.0 | .70 | .11 | .005 | 14.6 | .61 | 99.6 |
| | Σ EPAP bled idle | | 9.56 | | 1.12 | | 3.30 | |
| | Σ EPAP unbled idle | | 6.25 | | .64 | | 3.48 | |
| | Cruise no. 1 | 26.7 | | .09 | | 7.1 | | 99.4 |
| | Cruise no. 2 | 12.7 | | .15 | | 8.2 | | 99.7 |

NOTE: All data extrapolated to JT9D-7 engine pressures.

TABLE XX. - PHASE II HYBRID COMBUSTOR CONFIGURATIONS, ENGINE MODE CONTRIBUTIONS TO EPAP NUMBERS AND TOTAL EPAP NUMBERS.

| ENGINE OPERATING MODE | | IDLE CONTRIBUTION | | | APPROACH CONTRIBUTION | | | CLIMBOUT CONTRIBUTION | | | TAKE-OFF CONTRIBUTION | | | TOTAL EPAP NUMBER | | |
|-----------------------|------------------------|----------------------|-------|-------|--------------------------|-------|-------|--------------------------|-------|-------|--------------------------|-------|-------|-------------------|-------|-------|
| | | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx |
| 1979 EPA STANDARDS | LOWEST COMBINED VALUES | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 4.3 | 0.8 | 3.0 |
| JT9D-7 ENGINE | LOWEST COMBINED VALUES | 13.58 | 5.25 | 0.58 | 0.65 | 0.07 | 0.57 | 0.05 | 0.01 | 2.44 | 0.01 | -0- | 1.30 | 14.29 | 5.34 | 4.9 |
| CONFIGURATION H-1 | LOWEST NOx VALUES | 2.27 | 1.50 | 0.50 | ----- | ----- | ----- | ----- | ----- | ----- | 1.40 | 0.39 | 0.56 | ----- | ----- | ----- |
| | LOWEST CO & THC VALUES | " | " | " | ----- | ----- | ----- | ----- | ----- | ----- | 0.06 | 0.08 | 0.66 | ----- | ----- | ----- |
| | LOWEST COMBINED VALUES | " | " | " | ----- | ----- | ----- | ----- | ----- | ----- | " | " | " | ----- | ----- | ----- |
| CONFIGURATION H-2 | LOWEST NOx VALUES | 2.01 | 0.15 | 0.61 | 7.30 | 16.32 | 0.14 | 1.87 | 0.14 | 1.10 | 0.14 | 0.007 | 0.60 | 11.32 | 16.62 | 2.45 |
| | LOWEST CO & THC VALUES | " | " | " | 2.73 | 15.62 | 0.28 | " | " | " | " | " | " | 6.75 | 15.92 | 2.59 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 6.75 | 15.92 | 2.59 |
| CONFIGURATION H-3 | LOWEST NOx VALUES | 3.97 | 1.09 | 0.47 | 0.78 | 0.07 | 0.46 | ----- | ----- | ----- | -0- | -0- | 0.61 | ----- | ----- | ----- |
| | LOWEST CO & THC VALUES | 1.39 | 0.06 | 0.56 | 0.01 | 0.06 | 0.56 | ----- | ----- | ----- | " | " | " | ----- | ----- | ----- |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | ----- | ----- | ----- | " | " | " | ----- | ----- | ----- |
| CONFIGURATION H-4 | LOWEST NOx VALUES | 1.53 | 0.10 | 0.53 | 2.97 | 0.08 | 0.45 | 9.55 | 4.35 | 1.90 | 0.004 | -0- | 1.00 | 14.05 | 4.53 | 3.88 |
| | LOWEST CO & THC VALUES | " | " | " | 0.02 | 0.02 | 0.56 | 6.75 | 3.12 | 2.29 | " | " | " | 8.30 | 3.24 | 4.38 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 8.30 | 3.24 | 4.38 |
| CONFIGURATION H-5 | LOWEST NOx VALUES | 2.79 | 0.12 | 0.68 | 9.35 | 6.00 | 0.24 | 2.30 | 0.16 | 1.05 | 2.18 | 0.68 | 0.67 | 16.62 | 6.96 | 2.64 |
| | LOWEST CO & THC VALUES | " | " | " | 0.01 | 0.09 | 0.77 | " | " | " | 0.21 | 0.01 | 0.71 | 5.31 | 0.38 | 3.21 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 5.31 | 0.38 | 3.21 |
| CONFIGURATION H-6 | LOWEST NOx VALUES | 0.62 | 0.49 | 0.50 | 2.85 | 0.11 | 0.45 | 2.30 | 0.02 | 1.23 | 0.37 | 0.05 | 0.68 | 6.14 | 0.66 | 2.86 |
| | LOWEST CO & THC VALUES | " | " | " | -0- | 0.01 | 0.97 | " | " | " | " | " | " | 3.29 | 0.57 | 3.37 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 3.29 | 0.57 | 3.37 |
| CONFIGURATION H-7 | LOWEST NOx VALUES | 7.56 | 0.77 | 0.54 | 1.49 | 0.05 | 0.65 | 1.97 | 0.17 | 1.50 | 0.24 | 0.01 | 0.66 | 11.26 | 1.00 | 3.35 |
| | LOWEST CO & THC VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 11.26 | 1.00 | 3.35 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 11.26 | 1.00 | 3.35 |

TABLE XXI. - PRATT & WHITNEY HYBRID COMBUSTOR, BEST POLLUTION

PERFORMANCE RESULTS

| Combustor configuration | Engine mode | CO | | THC | | NO _x | | Combustion efficiency, percent |
|-------------------------|--------------------|------|-------------------|-----|-------------------|-----------------|-------------------|--------------------------------|
| | | EI | EPAP contribution | EI | EPAP contribution | EI | EPAP contribution | |
| H-5 | Idle bled | 16.2 | 2.79 | 0.7 | 0.12 | 4.0 | 0.68 | 99.6 |
| | Approach* | .1 | .01 | 1.3 | .09 | 12.0 | .77 | 99.9 |
| | Climbout | 21.6 | 2.30 | 1.5 | .16 | 9.9 | 1.05 | 99.3 |
| | Take-off | 5.1 | .21 | .5 | .02 | 17.2 | .71 | 99.8 |
| | Σ EPAP | | 5.31 | | .39 | | 3.21 | |
| H-6 | Idle bled | 9.6 | 1.65 | 4.2 | 0.72 | 3.6 | 0.61 | 99.4 |
| | Idle unbled | 3.5 | .62 | 2.8 | .49 | 2.8 | .50 | 99.6 |
| | Approach* | 0 | 0 | .2 | .14 | 15.2 | .97 | 100 |
| | Climbout | 21.6 | 2.30 | 1.5 | .16 | 11.6 | 1.23 | 99.3 |
| | Take-off | 9.0 | .37 | 1.1 | .05 | 16.4 | .68 | 99.7 |
| | Σ EPAP bled idle | | 4.32 | | .94 | | 3.56 | |
| | Σ EPAP unbled idle | | 3.29 | | .71 | | 3.45 | |
| | Cruise | 34.6 | | 6.0 | | 7.5 | | 98.6 |

NOTES: * Pilot only fueled at approach; NO_x extrapolated to engine pressures by $P^{0.2}$.

All data extrapolated to JT9D-7 engine pressures.

TABLE XXII. - PHASE II DOUBLE/ANNULAR COMBUSTOR CONFIGURATIONS, ENGINE MODE CONTRIBUTIONS TO EPAP NUMBERS AND TOTAL EPAP NUMBERS.

| ENGINE OPERATING MODE: | | IDLE CONTRIBUTIONS | | | APPROACH CONTRIBUTIONS | | | CLIMBOUT CONTRIBUTIONS | | | TAKE-OFF CONTRIBUTIONS | | | TOTAL EPAP NUMBER | | |
|------------------------|------------------------|-----------------------|-------|-------|---------------------------|-------|-------|---------------------------|-------|-------|---------------------------|-------|-------|-------------------|-------|-------|
| | | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx | CO | THC | NOx |
| 1979 EPA STANDARDS | LOWEST COMBINED VALUES | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 4.3 | 0.8 | 3.0 |
| CP6-50 ENGINE | LOWEST COMBINED VALUES | 9.97 | 4.10 | 0.34 | 0.39 | 0.001 | 0.91 | 0.04 | 0.001 | 4.39 | 0.01 | 0.001 | 2.03 | 10.8 | 4.3 | 7.7 |
| CONFIGURATION D/A-1 | LOWEST NOx VALUES | 6.46 | 1.49 | 0.45 | 5.84 | 0.65 | 0.39 | 0.13 | 0.01 | 2.14 | 0.03 | -0- | 0.86 | 12.46 | 2.15 | 3.84 |
| | LOWEST CO & THC VALUES | " | " | " | 0.43 | 0.05 | 1.10 | 0.09 | 0.01 | 2.33 | 0.005 | -0- | 1.05 | 6.99 | 1.55 | 4.93 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.13 | 0.01 | 2.14 | 0.03 | -0- | 0.86 | 7.05 | 1.55 | 4.55 |
| CONFIGURATION D/A-2 | LOWEST NOx VALUES | 6.17 | 1.35 | 0.47 | 8.98 | 1.12 | 0.42 | 0.15 | 0.01 | 2.00 | 0.03 | 0.01 | 0.99 | 15.33 | 2.49 | 3.88 |
| | LOWEST CO & THC VALUES | " | " | " | 0.46 | 0.02 | 1.04 | 0.04 | 0.01 | 2.45 | 0.006 | 0.03 | 1.08 | 6.68 | 1.41 | 5.04 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.15 | 0.01 | 2.00 | 0.03 | 0.01 | 0.99 | 6.81 | 1.39 | 4.50 |
| CONFIGURATION D/A-3 | LOWEST NOx VALUES | 9.11 | 4.78 | 0.43 | 2.17 | 0.01 | 0.85 | 0.80 | 0.02 | 2.70 | 0.06 | 0.001 | 1.34 | 12.14 | 4.81 | 5.32 |
| | LOWEST CO & THC VALUES | " | " | " | " | " | " | 0.23 | 0.006 | 3.22 | 0.02 | 0.005 | 1.49 | 11.53 | 4.80 | 5.99 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.39 | 0.006 | 2.71 | 0.06 | 0.001 | 1.34 | 11.72 | 4.80 | 5.33 |
| CONFIGURATION D/A-4 | LOWEST COMBINED VALUES | 5.43 | 0.96 | 0.56 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| CONFIGURATION D/A-5 | LOWEST COMBINED VALUES | 5.39 | 0.33 | 5.03 | 1.15 | 0.003 | 0.71 | 0.20 | -0- | 2.31 | 1.23 | 0.002 | 1.23 | 7.97 | 0.34 | 4.75 |
| CONFIGURATION D/A-6 | LOWEST COMBINED VALUES | 3.41 | 0.29 | 0.51 | 0.43 | 0.003 | 0.89 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| CONFIGURATION D/A-7 | LOWEST COMBINED VALUES | 2.58 | 0.19 | 0.48 | 2.82 | 0.01 | 0.82 | 0.11 | 0.005 | 1.60 | 0.007 | 0.01 | 0.68 | 5.52 | 0.21 | 3.58 |
| CONFIGURATION D/A-8 | LOWEST NOx VALUES | 2.55 | 0.23 | 0.42 | 10.57 | 1.36 | 0.39 | 0.11 | 0.003 | 2.20 | 0.004 | -0- | 1.11 | 13.23 | 1.59 | 4.12 |
| | LOWEST CO & THC VALUES | " | " | " | 0.21 | 0.01 | 0.77 | 0.03 | 0.003 | 2.63 | " | " | " | 2.79 | 0.25 | 4.93 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.04 | 0.003 | 2.24 | " | " | " | 2.80 | 0.25 | 4.54 |
| CONFIGURATION D/A-9 | LOWEST NOx VALUES | 2.88 | 0.41 | 0.45 | 8.17 | 1.48 | 0.59 | 0.13 | 0.003 | 2.09 | 0.005 | -0- | 1.04 | 11.19 | 1.89 | 4.17 |
| | LOWEST CO & THC VALUES | " | " | " | 0.11 | 0.01 | 0.76 | 0.02 | -0- | 2.51 | -0- | 0.003 | 1.21 | 3.01 | 0.42 | 4.93 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.13 | 0.003 | 2.09 | " | " | " | 3.12 | 0.43 | 4.34 |
| CONFIGURATION D/A-10 | LOWEST NOx VALUES | 2.44 | 0.19 | 0.46 | 6.52 | 1.43 | 0.44 | 0.29 | 0.003 | 2.15 | 0.04 | -0- | 1.11 | 9.29 | 1.62 | 4.16 |
| | LOWEST CO & THC VALUES | " | " | " | 0.17 | -0- | 0.78 | 0.26 | 0.003 | 2.61 | 0.01 | -0- | 1.15 | 2.88 | 0.19 | 5.00 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.29 | 0.003 | 2.15 | 0.04 | -0- | 1.11 | 2.94 | 0.19 | 4.50 |
| CONFIGURATION D/A-11 | LOWEST NOx VALUES | 2.80 | 0.34 | 0.44 | 7.35 | 0.75 | 0.25 | 0.03 | 0.003 | 2.24 | 0.004 | 0.001 | 1.13 | 10.18 | 1.09 | 4.06 |
| | LOWEST CO & THC VALUES | " | " | " | 0.15 | 0.003 | 0.79 | 0.01 | 0.003 | 2.35 | 0.002 | -0- | 1.35 | 2.96 | 0.35 | 4.93 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.03 | 0.003 | 2.24 | 0.004 | 0.001 | 1.13 | 2.98 | 0.35 | 4.60 |
| CONFIGURATION D/A-12 | LOWEST NOx VALUES | 3.00 | 0.39 | 0.43 | 0.98 | 0.13 | 0.63 | 0.13 | 0.006 | 2.18 | 0.004 | -0- | 1.10 | 4.11 | 0.53 | 4.34 |
| | LOWEST CO & THC VALUES | " | " | " | 0.31 | 0.008 | 0.80 | 0.02 | 0.006 | 2.61 | 0.003 | -0- | 1.28 | 3.33 | 0.40 | 5.12 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.04 | 0.006 | 2.20 | 0.004 | -0- | 1.10 | 3.35 | 0.40 | 4.53 |

TABLE XXII - DOUBLE/ANNULAR COMBUSTOR DATA cont.

| ENGINE OPERATING MODE: | | IDLE CONTRIBUTION | | | APPROACH CONTRIBUTION | | | CLIMBOUT CONTRIBUTION | | | TAKE-OFF CONTRIBUTION | | | TOTAL EPAP NUMBER | | |
|------------------------|-------------------------------|----------------------|------|-----------------|--------------------------|-------|-----------------|--------------------------|-----|-----------------|--------------------------|-------|-----------------|-------------------|------|-----------------|
| | | CO | THC | NO _x | CO | THC | NO _x | CO | THC | NO _x | CO | THC | NO _x | CO | THC | NO _x |
| CONFIGURATION D/A-13 | LOWEST NO _x VALUES | 2.64 | 0.30 | 0.41 | 3.63 | 0.68 | 0.55 | 0.06 | -0- | 1.97 | 0.03 | 0.003 | 0.96 | 6.36 | 0.98 | 3.89 |
| | LOWEST CO & THC VALUES | " | " | " | 0.28 | 0.003 | 0.81 | 0.03 | -0- | 2.22 | 0.003 | -0- | 1.16 | 2.95 | 0.30 | 4.60 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 0.06 | -0- | 0.96 | 0.03 | 0.003 | 0.96 | 3.01 | 0.31 | 4.15 |
| CONFIGURATION D/A-14a | LOWEST NO _x VALUES | 3.66 | 0.41 | 0.44 | 9.25 | 1.17 | 0.43 | 0.11 | -0- | 2.53 | 0.01 | 0.002 | 1.20 | 13.03 | 1.58 | 4.60 |
| | LOWEST CO & THC VALUES | " | " | " | 0.25 | 0.02 | 0.69 | 0.05 | -0- | 2.84 | " | " | " | 3.97 | 0.43 | 5.17 |
| | LOWEST COMBINED VALUES | " | " | " | 0.35 | 0.02 | 0.77 | 0.11 | -0- | 2.53 | " | " | " | 4.13 | 0.43 | 4.84 |
| CONFIGURATION D/A-14b | LOWEST NO _x VALUES | 6.45 | 2.66 | 0.42 | 0.47 | 0.01 | 0.82 | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | LOWEST CO & THC VALUES | " | " | " | 0.41 | 0.004 | 0.80 | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | LOWEST COMBINED VALUES | " | " | " | 0.47 | 0.01 | 0.82 | --- | --- | --- | --- | --- | --- | --- | --- | --- |

TABLE XXIII. - GENERAL ELECTRIC DOUBLE/ANNULAR COMBUSTOR BEST POLLUTION

PERFORMANCE DATA

| Combustor configuration | Engine mode | CO | | THC | | NO _x | | Combustion efficiency, percent |
|-------------------------|-------------------------------------|------|-------------------|------|-------------------|-----------------|-------------------|--------------------------------|
| | | EI | EPAP contribution | EI | EPAP contribution | EI | EPAP contribution | |
| D/A-13 | Idle | 19.3 | 2.64 | 2.2 | 0.30 | 3.0 | 0.41 | 99.3 |
| | Approach pilot only* | 3.1 | .28 | .03 | .003 | 12.8 | .81 | 99.9 |
| | Approach pilot and one-half main | 11.5 | 1.05 | 2.49 | .22 | 6.25 | .57 | 99.5 |
| | Climbout | .41 | .06 | 0 | 0 | 13.3 | 1.97 | 100 |
| | Take-off | .52 | .03 | .1 | .003 | 16.9 | .96 | 100 |
| | Σ EPAP pilot only approach | | 3.01 | | .31 | | 4.15 | |
| | Σ EPAP pilot one-half main approach | | 3.78 | | .53 | | 3.91 | |
| | Cruise | 8.8 | | .2 | | 8.0 | | 99.8 |
| D/A-10 | Idle | 17.9 | 2.44 | 1.4 | 0.19 | 3.4 | 0.46 | 99.4 |
| | Approach* | 1.9 | .17 | 0 | 0 | 8.6 | .78 | 100 |
| | Climbout | 1.92 | .29 | 0 | .003 | 14.5 | 2.15 | 100 |
| | Take-off | .7 | .04 | 0 | 0 | 19.5 | 1.11 | 100 |
| | Σ EPAP | | 2.94 | | .19 | | 4.50 | |

NOTES: All data extrapolated to CF6-50 engine pressures.

*Pilot only fueled at approach; NO_x extrapolated to engine pressures by $P^{0.2}$.

ORIGINAL PAGE
OF POOR QUALITY

TABLE XXIV. - PHASE II RADIAL/AXIAL COMBUSTOR CONFIGURATIONS, ENGINE MODE CONTRIBUTIONS TO EPAP NUMBERS AND TOTAL EPAP NUMBERS.

| ENGINE OPERATING MODE: | | IDLE CONTRIBUTION | | | APPROACH CONTRIBUTION | | | CLIMBOUT CONTRIBUTION | | | TAKE-OFF CONTRIBUTION | | | TOTAL EPAP NUMBER | | |
|------------------------|-------------------------------|----------------------|-------|-----------------|--------------------------|-------|-----------------|--------------------------|-------|-----------------|--------------------------|-------|-----------------|-------------------|-------|-----------------|
| | | CO | THC | NO _x | CO | THC | NO _x | CO | THC | NO _x | CO | THC | NO _x | CO | THC | NO _x |
| 1979 EPA STANDARDS | LOWEST COMBINED VALUES | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 4.3 | 0.8 | 3.0 |
| CF6-50 ENGINE | LOWEST COMBINED VALUES | 9.97 | 4.10 | 0.34 | 0.39 | 0.001 | 0.91 | 0.04 | 0.001 | 4.39 | 0.01 | 0.001 | 2.03 | 10.8 | 4.3 | 3.0 |
| CONFIGURATION R/A-1 | LOWEST NO _x VALUES | 12.40 | 4.63 | 0.28 | 7.63 | 4.52 | 0.40 | 6.10 | 0.38 | 1.71 | 0.79 | 0.03 | 0.67 | 26.9 | 9.56 | 3.06 |
| | LOWEST CO & THC VALUES | 11.77 | 3.93 | 0.31 | 0.25 | 0.02 | 0.63 | 2.90 | 0.07 | 3.47 | 0.17 | 0.002 | 1.89 | 15.09 | 4.02 | 6.30 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | 0.70 | 0.03 | 0.69 | 15.62 | 4.05 | 5.10 |
| CONFIGURATION R/A-2 | LOWEST NO _x VALUES | 7.35 | 0.83 | 0.43 | 9.92 | 8.54 | 0.18 | 1.62 | 0.03 | 2.11 | 0.48 | 0.01 | 0.92 | 19.37 | 9.41 | 3.63 |
| | LOWEST CO & THC VALUES | " | " | " | 0.11 | 0.01 | 0.84 | 0.96 | 0.01 | 3.18 | 0.10 | 0.002 | 1.42 | 8.52 | 0.85 | 5.87 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | 0.10 | 0.002 | 1.42 | 8.52 | 0.85 | 5.87 |
| CONFIGURATION R/A-3 | LOWEST NO _x VALUES | 6.24 | 0.37 | 0.41 | 0.08 | 0.01 | 0.70 | 7.11 | 1.65 | 1.25 | 0.88 | 0.08 | 0.67 | 14.31 | 2.11 | 3.03 |
| | LOWEST CO & THC VALUES | " | " | " | " | " | " | 2.35 | 0.10 | 3.02 | 0.12 | 0.01 | 1.31 | 8.79 | 0.49 | 5.44 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | 0.36 | 0.02 | 0.81 | 9.03 | 0.50 | 4.94 |
| CONFIGURATION R/A-4 | LOWEST NO _x VALUES | 5.84 | 0.20 | 0.43 | 0.14 | 0.02 | 0.51 | 8.09 | 2.28 | 0.77 | 1.94 | 0.27 | 0.49 | 16.01 | 2.77 | 2.20 |
| | LOWEST CO & THC VALUES | " | " | " | " | " | " | 4.42 | 0.15 | 3.36 | 0.49 | 0.01 | 1.25 | 10.89 | 0.38 | 5.55 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | 5.10 | 0.23 | 2.32 | " | " | " | 11.57 | 0.46 | 4.51 |
| CONFIGURATION R/A-5 | LOWEST NO _x VALUES | 7.74 | 0.36 | 0.42 | 0.09 | 0.02 | 0.72 | 7.78 | 2.26 | 0.61 | 1.32 | 0.03 | 1.05 | 16.93 | 2.67 | 2.80 |
| | LOWEST CO & THC VALUES | " | " | " | " | " | " | 3.24 | 0.12 | 1.71 | 1.00 | 0.04 | 1.31 | 12.07 | 0.54 | 4.16 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 12.07 | 0.54 | 4.16 |
| CONFIGURATION R/A-6 | LOWEST NO _x VALUES | 3.26 | 0.07 | 0.39 | 7.55 | 10.22 | 0.15 | 1.71 | 0.03 | 2.02 | ----- | ----- | ----- | ----- | ----- | ----- |
| | LOWEST CO & THC VALUES | " | " | " | 0.06 | 0.003 | 0.84 | " | " | " | ----- | ----- | ----- | ----- | ----- | ----- |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | ----- | ----- | ----- | ----- | ----- | ----- |
| CONFIGURATION R/A-7 | LOWEST NO _x VALUES | 7.10 | 1.17 | 0.36 | 0.01 | 0.005 | 0.64 | 6.16 | 5.07 | 0.24 | 2.04 | 0.30 | 0.39 | 15.31 | 6.55 | 1.63 |
| | LOWEST CO & THC VALUES | " | " | " | " | " | " | 4.03 | 0.33 | 1.06 | 0.74 | 0.04 | 0.54 | 11.88 | 1.55 | 2.60 |
| | LOWEST COMBINED VALUES | " | " | " | " | " | " | " | " | " | " | " | " | 11.88 | 1.55 | 2.60 |

TABLE XXV. - GENERAL ELECTRIC RADIAL/AXIAL COMBUSTOR BEST POLLUTION PERFORMANCE DATA

| Combustor configuration | Engine mode | CO | | THC | | NO _x | | Combustion efficiency, percent |
|-------------------------|-----------------------------|------|-------------------|------|-------------------|-----------------|-------------------|--------------------------------|
| | | EI | EPAP contribution | EI | EPAP contribution | EI | EPAP contribution | |
| R/A - 2 | Idle | 53.8 | 7.35 | 6.1 | 0.83 | 3 | 0.43 | 98.1 |
| Climbout F/A = 0.0074 | Approach pilot only* | 1.3 | .11 | .2 | .01 | 9.2 | .84 | 100 |
| Take-off F/A = 0.0069 | Climbout | 6.4 | .96 | .1 | .01 | 21.4 | 3.18 | 99.8 |
| | Take-off | 1.8 | .10 | .03 | .002 | 24.9 | 1.42 | 100 |
| | Σ EPAP | | 8.52 | | .852 | | 5.87 | |
| | Cruise | 29.1 | | 2.47 | | 7.2 | | 99.1 |
| | Cruise one-half main fueled | 29.8 | | 2.47 | | 6.84 | | 99.1 |
| R/A - 2 | Idle | 53.8 | 7.35 | 6.1 | 0.83 | 3 | 0.43 | 98.1 |
| Climbout F/A = 0.0049 | Approach pilot only* | 1.3 | .11 | .2 | .01 | 9.2 | .84 | 100 |
| Climbout F/A = 0.0039 | Climbout | 10.9 | 1.62 | .2 | .03 | 14.2 | 2.11 | 99.8 |
| | Take-off | 8.5 | .48 | .1 | .01 | 16.1 | .92 | 99.8 |
| | Σ EPAP | | 9.56 | | .88 | | 4.30 | |

NOTE: All data extrapolated to CF6-50 engine pressures.

*Pilot only fueled at approach; NO_x extrapolated to engine pressures by $P^{0.2}$.

TABLE XXVI. - STEADY STATE PERFORMANCE/EMISSION TESTS POINTS

| MAIN POWER POINTS ENGINE CONDITIONS | | IDLE | | | APPROACH | | | CLIMBOUT | | TAKEOFF |
|--|----------|------|-----------|--------------|----------|---------------|--------------|----------|-------------|---------|
| SECONDARY POWER ENGINE CONDITIONS | SUB-IDLE | | RICH-IDLE | SUB-APPROACH | | RICH APPROACH | SUB-CLIMBOUT | | SUB-TAKEOFF | |
| PRIMARY/SECONDARY FUEL STAGING POINTS | | | | | (2X) | | | (2X) | | (2X) |
| 12-POINT FIXED POLLUTION SAMPLING | | X | | | X | | | X | | X |
| 24-POINT FIXED POLLUTION SAMPLING | X | X | X | X | (3X) | X | X | (3X) | X | (3X) |
| TRAVERSE SAMPLING | | X | | | X | | | X | | X |

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TOTALS:

A. Total Engine Points Investigated

1. 16 Total Engine Conditions
2. Single Fuel Scheduling at:
 - a. Sub-idle
 - b. Idle
 - c. Rich idle
 - d. Sub-approach
 - e. Rich approach
 - f. Sub-climbout
 - g. Sub-takeoff
3. 3-Fuel Splits Investigated at:
 - a. Approach (approximately 30% power)
 - b. Climbout (approximately 85% power)
 - c. Takeoff (100% power)

B. Pollution Sampling

1. 12-point Fixed Sampling - 4 EPAP settings
2. 24-point Fixed Sampling - all engine conditions,
16 total test points
3. Traverse Sampling - 4 test points, EPAP settings

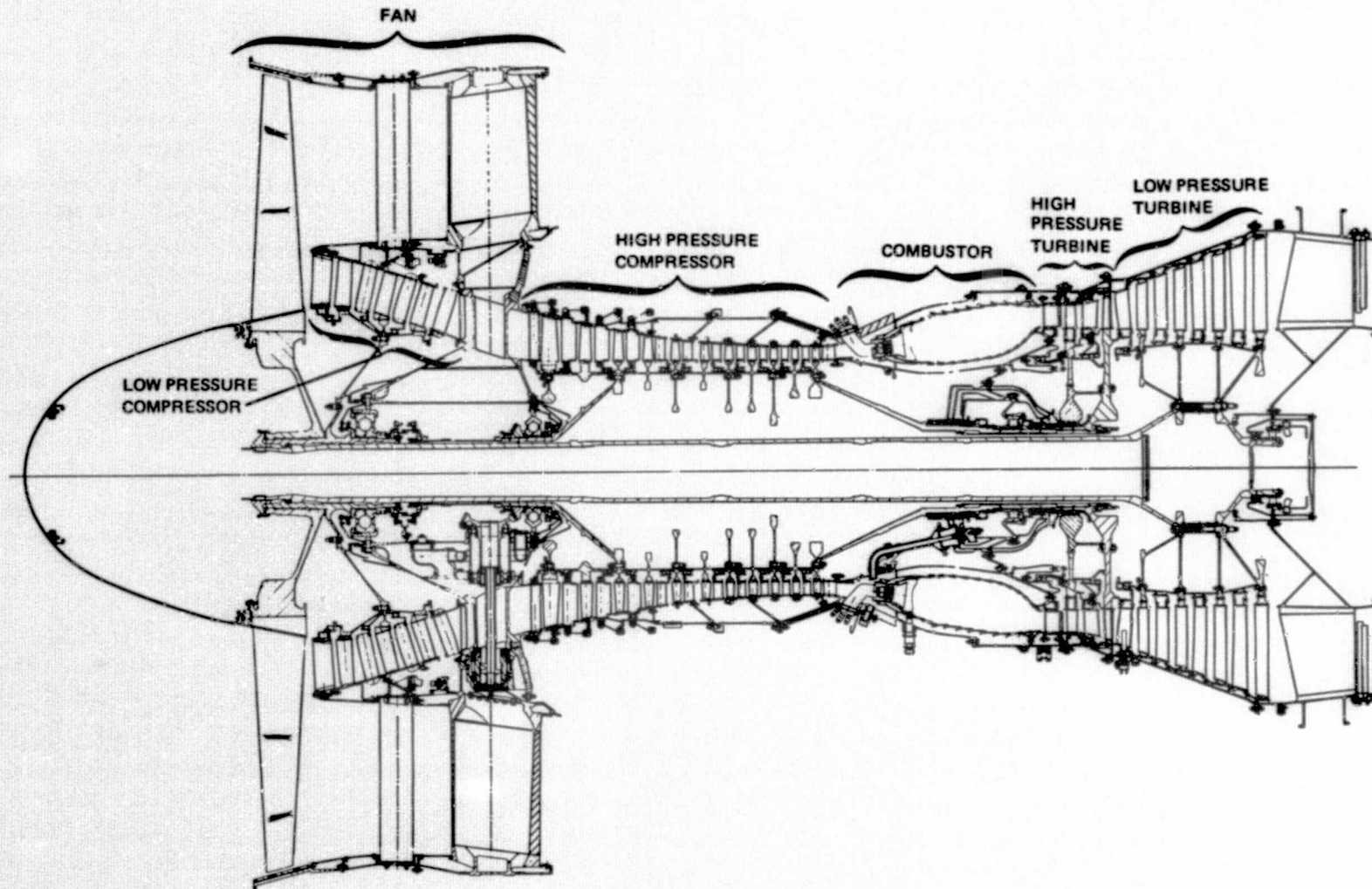


Figure 1. - Cross-sectional schematic of the JT9D-7 reference engine.

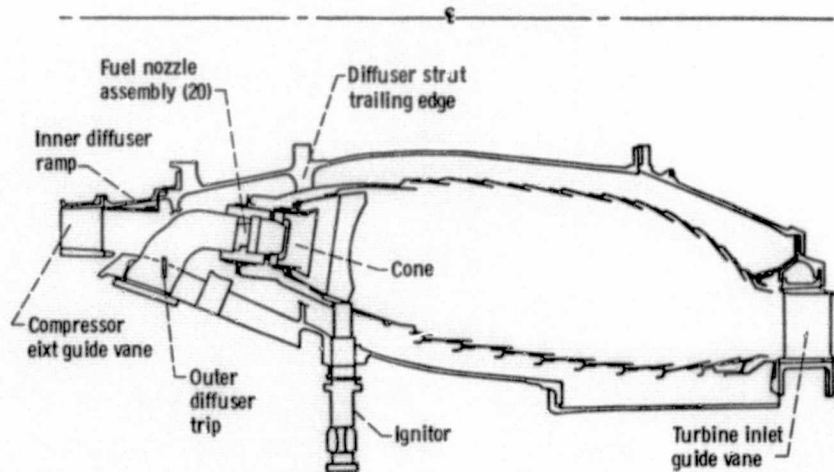


Figure 2. - Cross-sectional schematic of the JT9D-7 reference combustor.

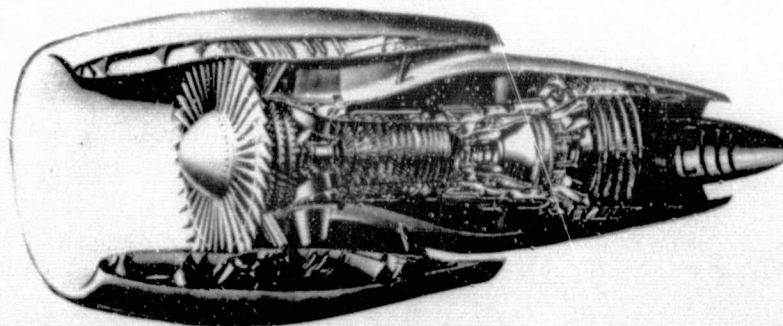


Figure 3. - General Electric CF6-50 High Bypass Turbofan Engine.

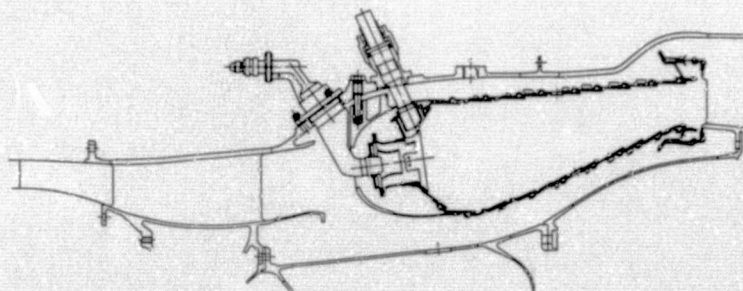
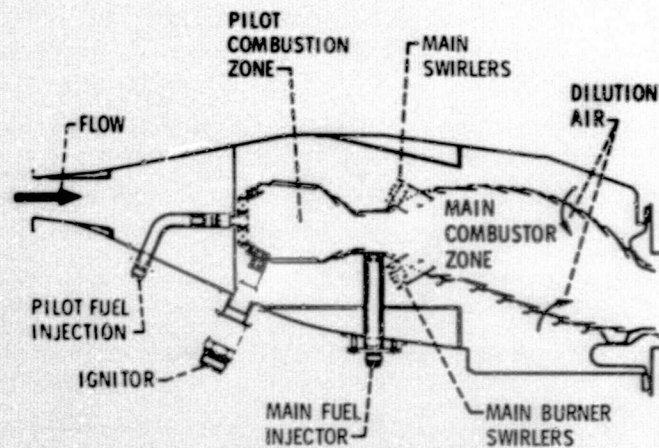
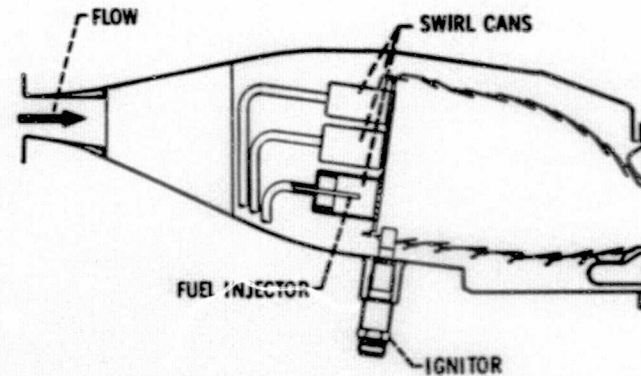


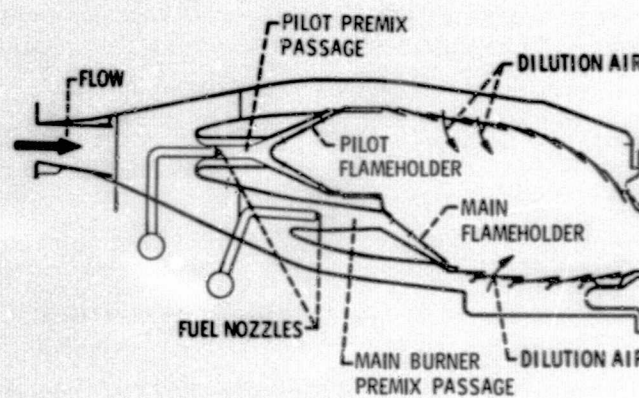
Figure 4. - Production CF6-50 engine combustor.



VORBIX COMBUSTOR FOR JT9D ENGINE



SWIRL-CAN MODULAR COMBUSTOR, FOR JT9D ENGINE



STAGED PREMIX COMBUSTOR, JT9D ENGINE

Figure 5. - Pratt & Whitney phase I combustor concepts for the JT9D-7 engine.

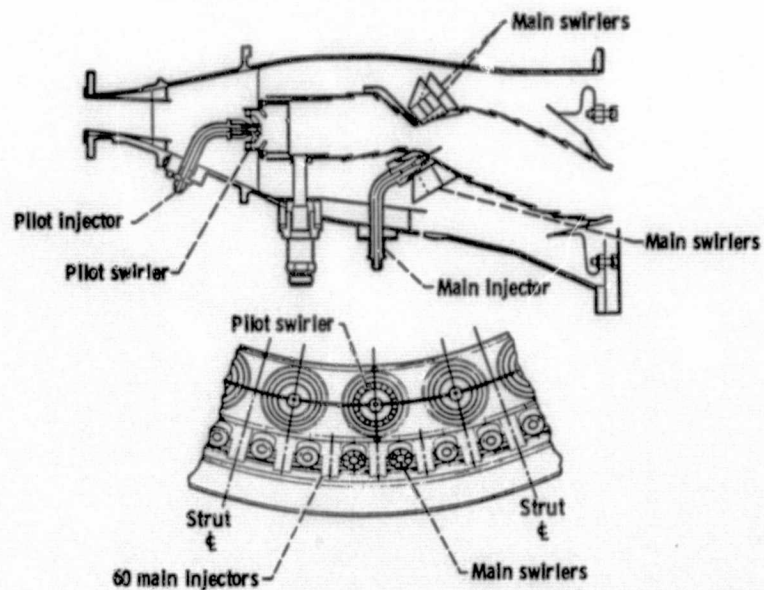
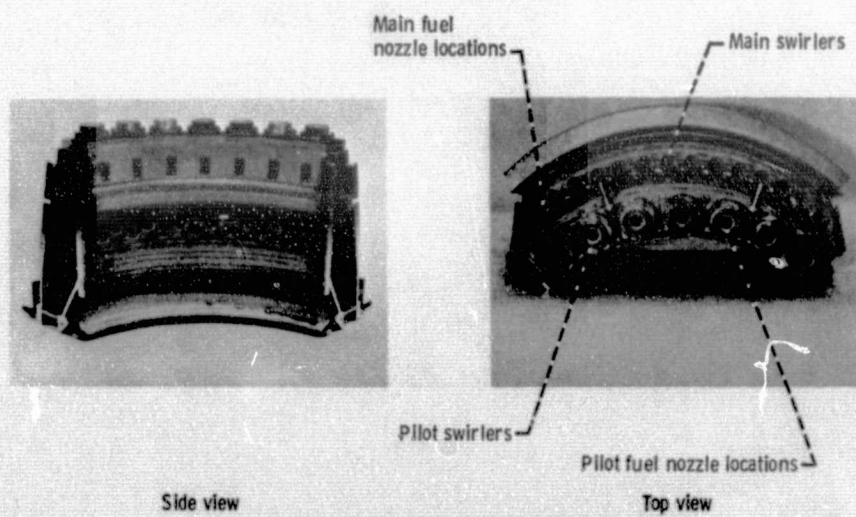


Figure 6-a. - Phase II Vorbix Combustor, P. & W.

J12478-25
H752406



Side view

Top view

Figure 6-b. - Phase II Vorbix Combustor, P. & W.

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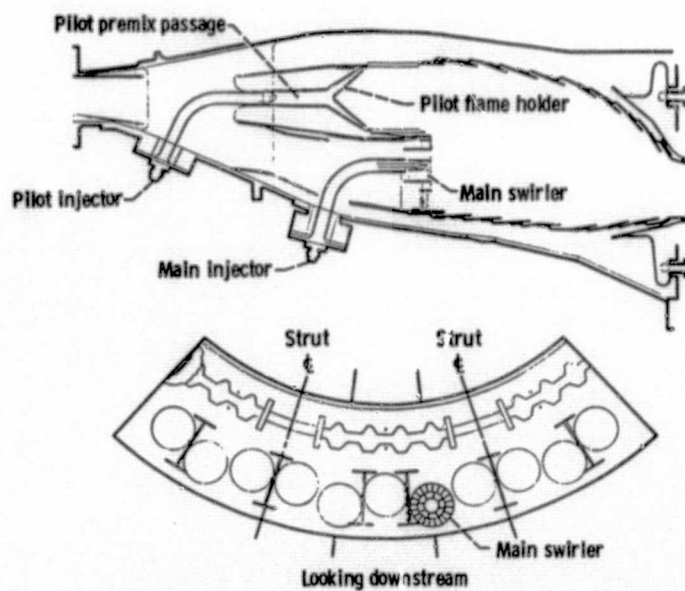


Figure 7-a. - Phase II Hybrid Combustor, P. & W.

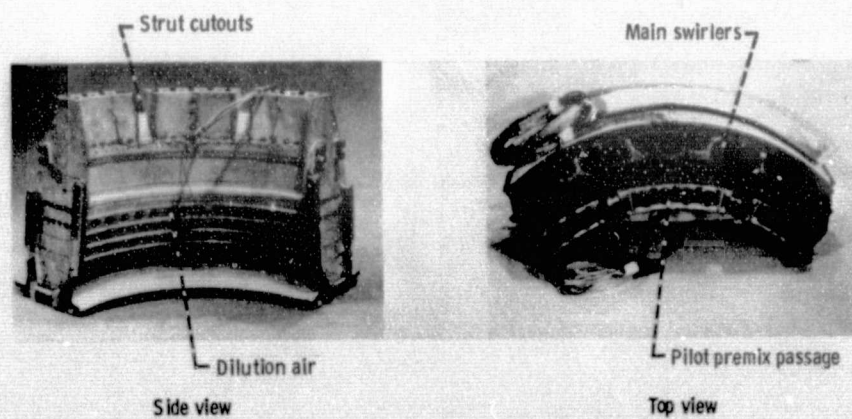
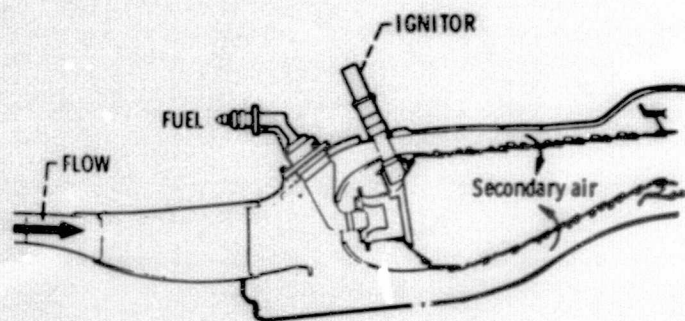
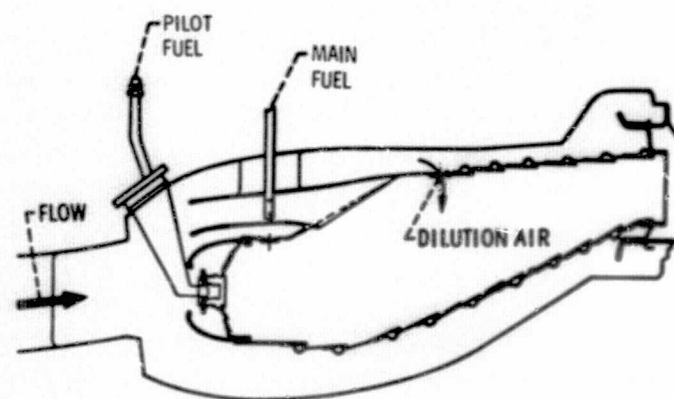


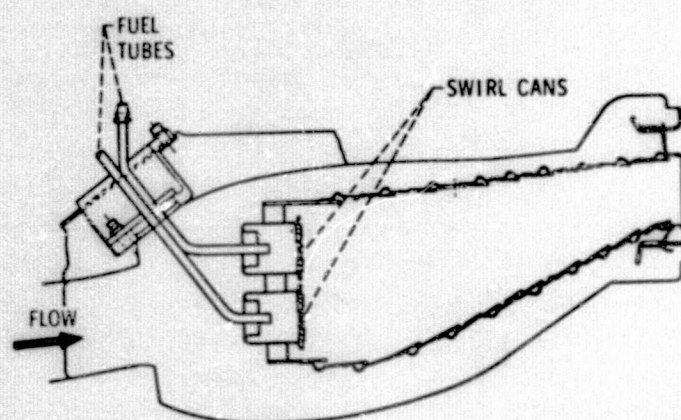
Figure 7-b. - Phase II Hybrid Combustor, P. & W.



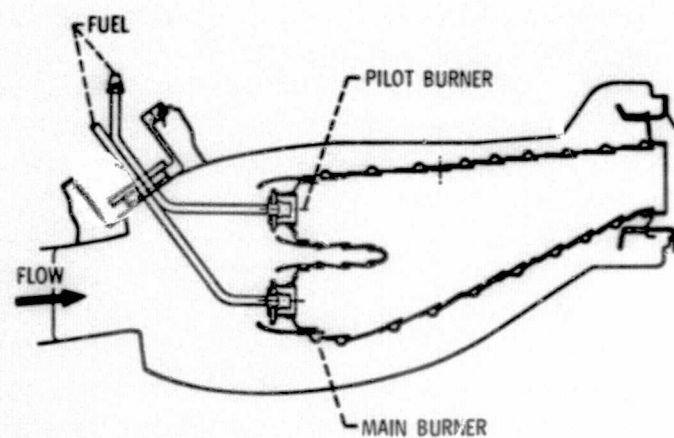
SINGLE ANNULUS - LEAN DOME COMBUSTOR, CF6-50 ENGINE



RADIAL/AXIAL STAGED COMBUSTOR, CF6-50 ENGINE



NASA SWIRL CAN MODULAR COMBUSTOR FOR CF6-50 ENGINE



DOUBLE-ANNULAR LEAN DOME COMBUSTOR, CF6-50 ENGINE

Figure 8. - Combustor concepts for the CF6-50 engine, GE.

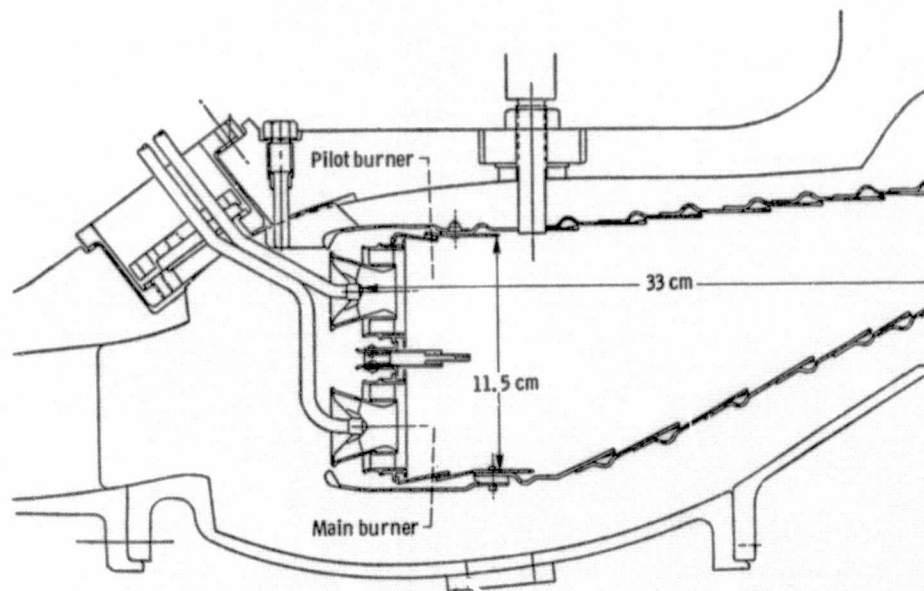


Figure 9-a. - Phase II Double/Annular Combustor, G.E.

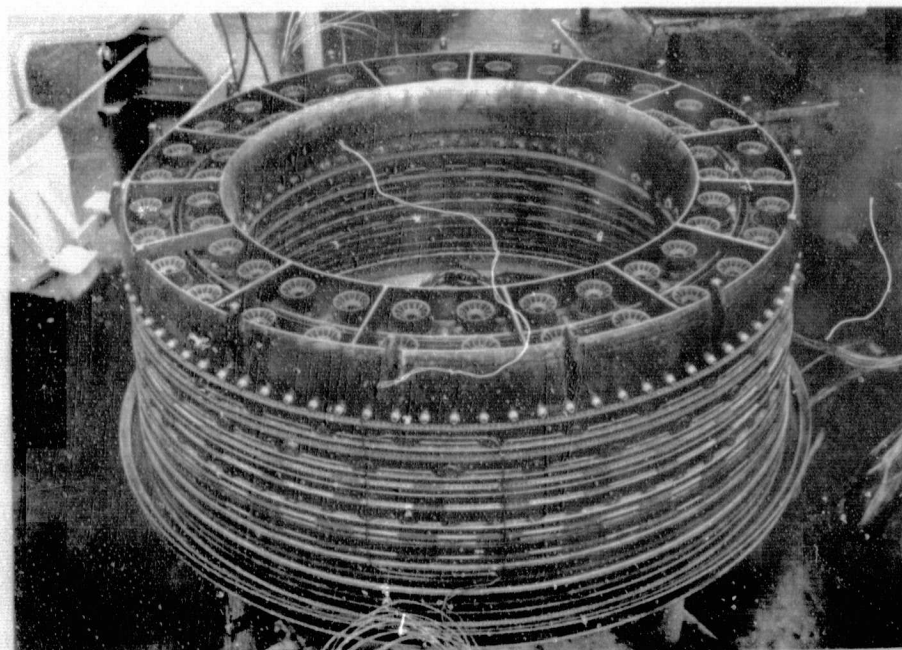
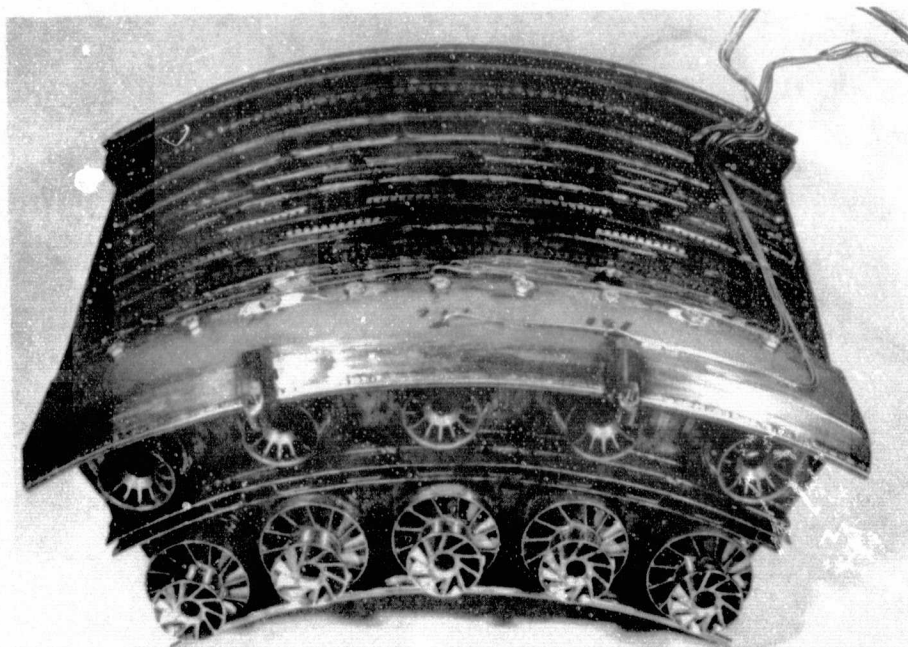


Figure 9-b. - Phase II Double/Annular Combustor, G.E.

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Front view

Figure 9-c. - Phase II Double/Annular Combustor, 60° sector relight model, G.E.

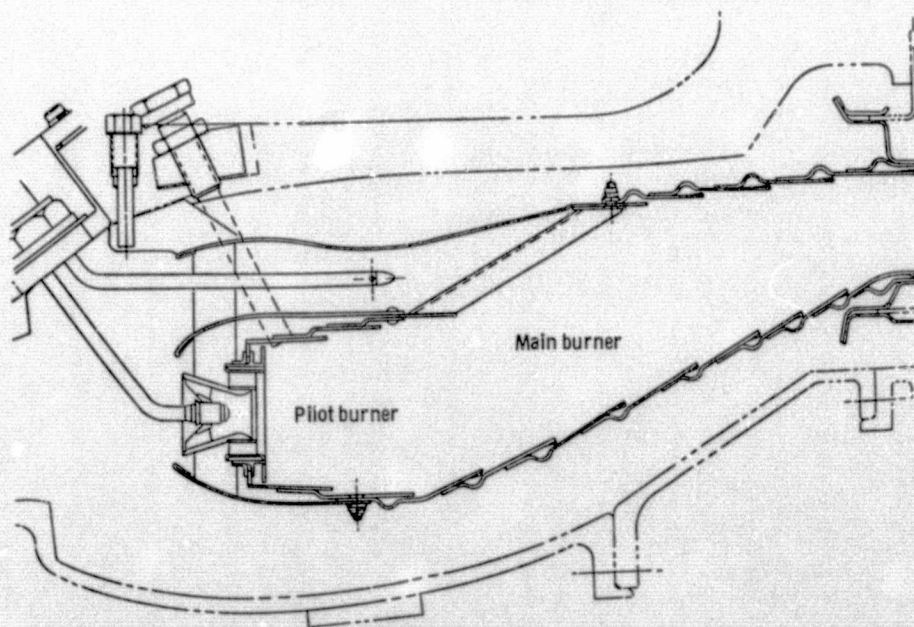


Figure 10-a. - Phase II Radial/Axial Combustor, G.E.

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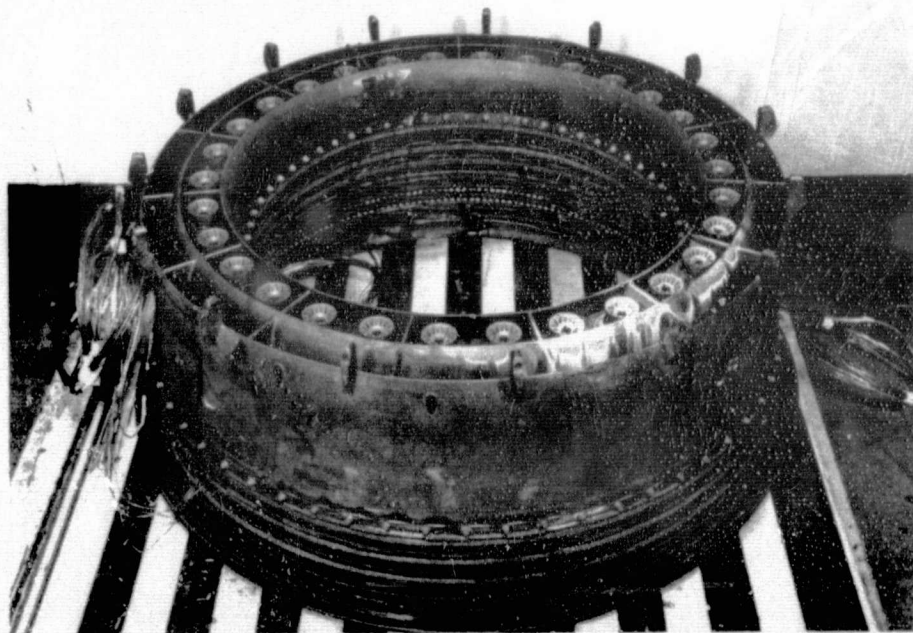


Figure 10-b. - Phase II Radial/Axial Combustor, G. E.

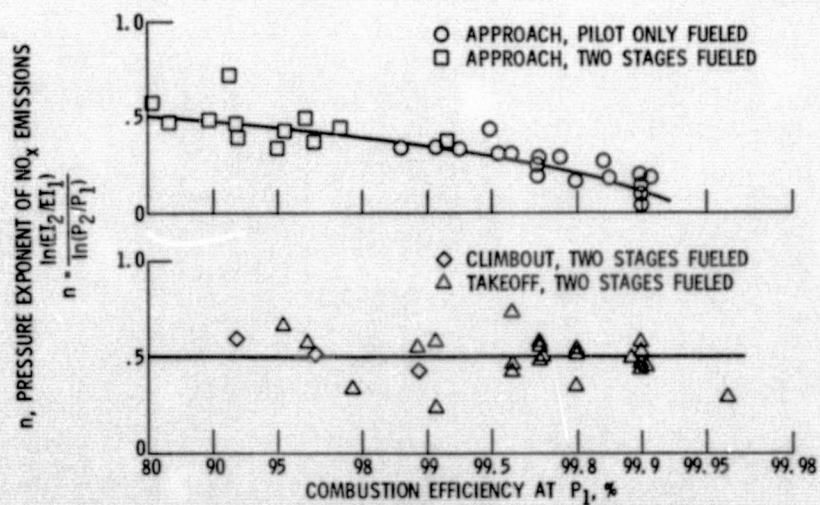


Figure 11. - Effect of combustion efficiency on NO_x pressure exponent, ECCP phase II test configurations.

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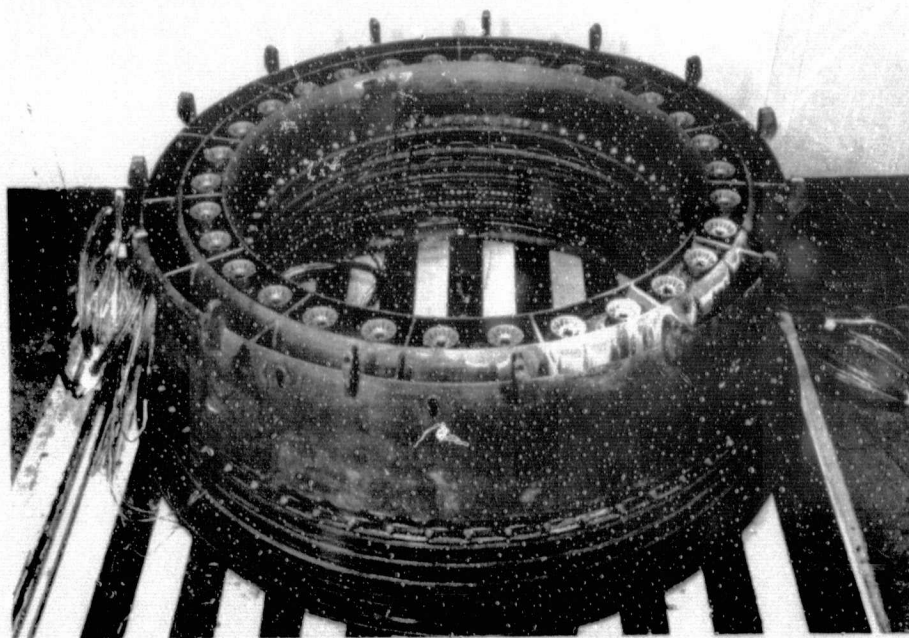


Figure 10-b. - Phase II Radial/Axial Combustor, G. E.

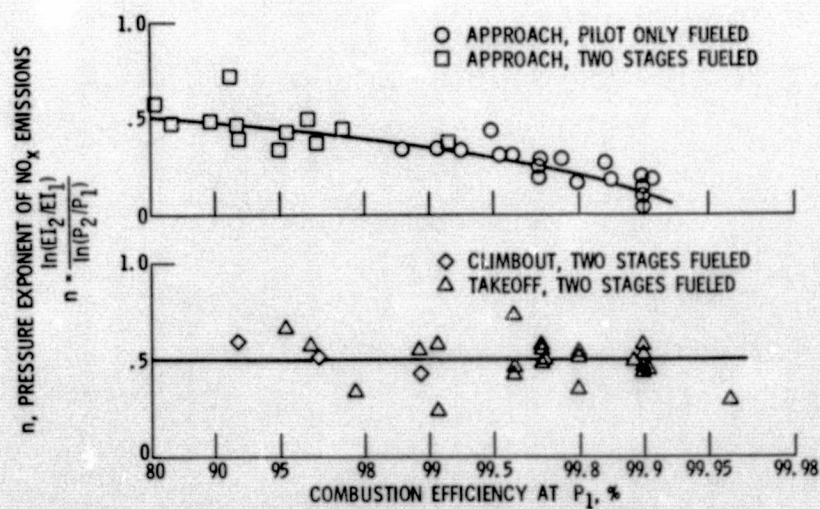


Figure 11. - Effect of combustion efficiency on NO_x pressure exponent, ECCP phase II test configurations.

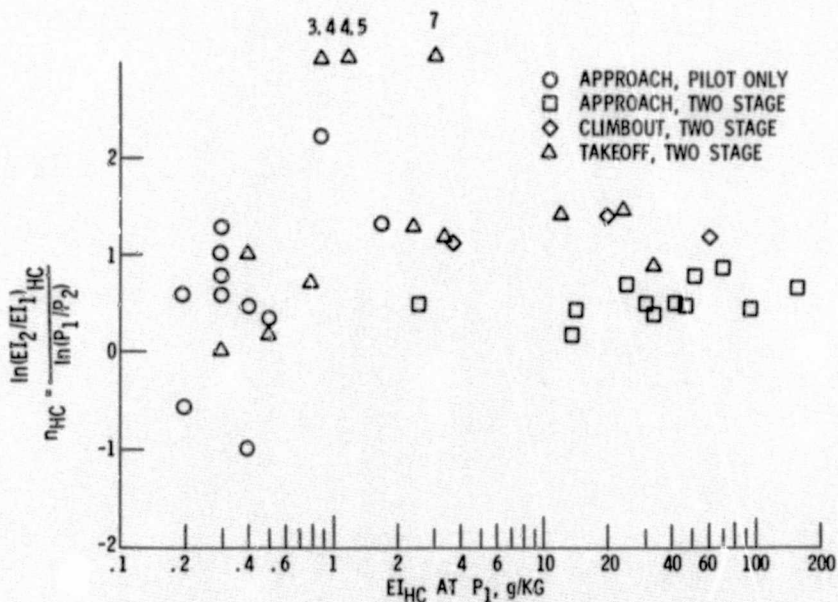


Figure 12. - Effect of pressure on HC emissions.

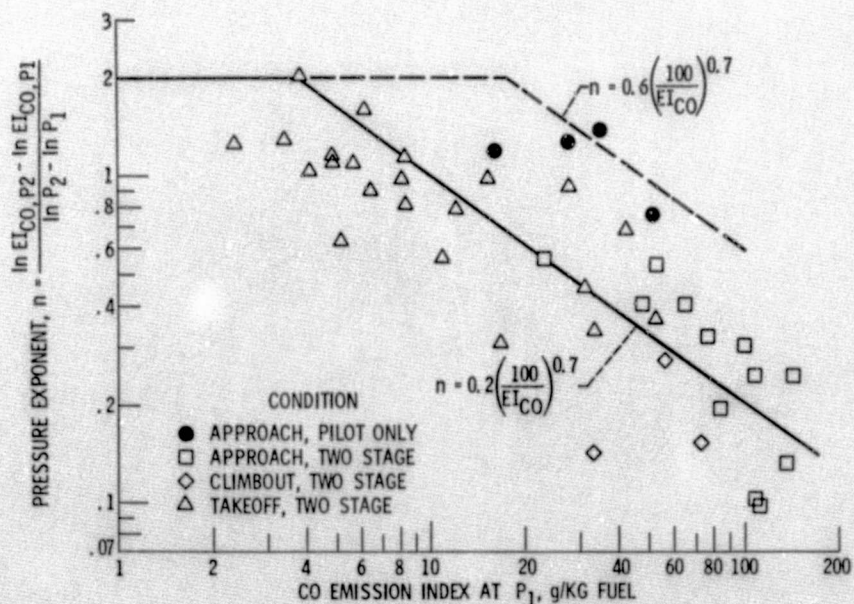


Figure 13. - Effect of pressure on CO emission index, all ECCP II tests.